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Determining F-Factor Using Ground-Based Doppler Radar: Validation and Results.

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F-Factor Determination Using Ground-Based Doppler Radar: Validation and Results

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National Center for Atmospheric Research

Using a two-dimensional linear least-squares method applied to Doppler radar data, we test the viability of determining F-factor remotely. The ultimate application of such an algorithm will be supplying real-time F-factor maps, derived from ground-based Doppler radars to air traffic control personnel and pilots. Data from NASA deployments to the MIT/Lincoln Lab TDWR testbed radar in Orlando in 1991 and 1992 along with NASA deployments to the NCAR TDWR testbed radar in Denver are examined. Preliminary analyses show that the two-dimensional method correlates reasonably well with *in situ* measurements. Several effects, independent of the method used, act to reduce the correlation to less than 1. These include time differences between radar and aircraft data, vertical misalignment between the aircraft and the radar beam, different spatial resolution scales between aircraft and radar data, inhomogeneous radar beam filling, noise in radar data that eludes filtering and phase lag between time and space due to low pass filtering of the aircraft data. In the final assessment, it appears that a shear-based F-factor algorithm is preferable to the currently implemented TDWR algorithms which lack any local shear estimates.

Problem: Develop a windshear hazard index, based on ground-based Doppler radar data, that quatitatively describes the expected aircraft performance loss along a given flight path.

Define the performance parameter as F, where

$$F=\frac{1}{g}\frac{\partial V}{\partial t}-\frac{w}{GS},$$

where:
- g is acceleration due to gravity
- V is the aircraft longitudinal wind component
- w is the vertical wind component
- GS is the aircraft ground speed.

Summer '92: NASA flies instrumented 737 through Denver and Orlando microbursts close to radar beam height. Compare *in situ* aircraft data to shear estimates using TDWR testbed radar. We estimate F by

$$F=\frac{1}{g}U_r GS-\frac{w}{GS}$$

where U_r is radial shear. U_r is estimated by a two dimensional least squares fit of the radial doppler velocity. We estimate w by

$$w=-2U_r Z$$

where Z is the height of the beam. We are assuming local symmetry of the microburst. This estimate for w is used at all points where we detect divergence ($U_r>0$).

Using weighted least squares, solve

and get

$$U_r = \frac{\Sigma i U_{i,j} W_{i,j}}{\Delta r \Sigma i^2 W_{i,j}}$$

$$U_s = \frac{\Sigma \Delta S_{i,j} U_{i,j} W_{i,j}}{\Sigma (\Delta S_{i,j})^2 W_{i,j}}$$

where

$$U_{i,j} = \text{radial velocity at } i, j,$$

$$\Delta S_{i,j} = r_i \phi_j \text{ and}$$

$$W_{i,j} = \text{weight.}$$

We estimate the horizontal F factor by

$$F_h = \frac{1}{g}\frac{\partial V}{\partial t} \approx \frac{1}{g} \cdot U_r \cdot GS$$

and the vertical F factor by

$$F_v = -\frac{w}{GS} \approx \frac{2\,U_r Z}{GS}$$

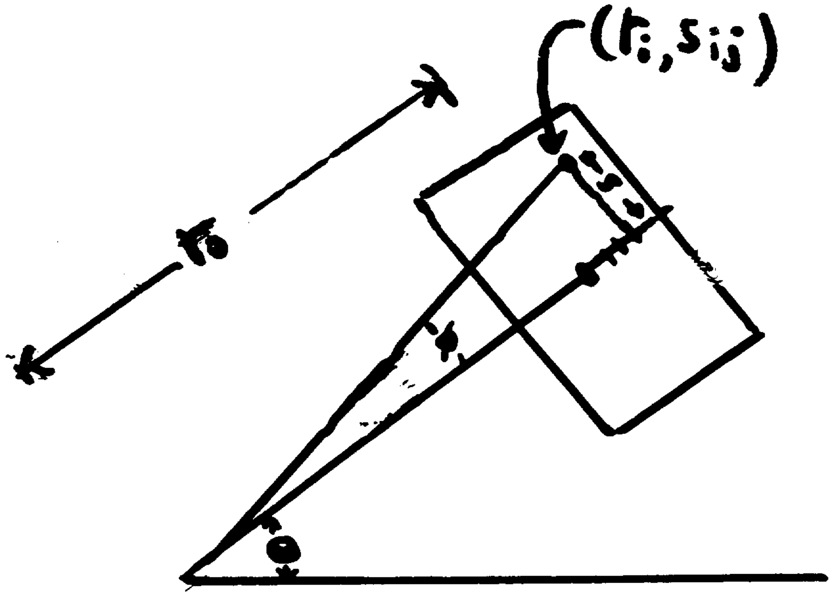
when we detect divergence and

$$F_v = \frac{U_r Z}{GS}$$

when we detect convergence.

Total F is approximated by

$$F = F_h + F_v .$$



$s = r\phi$

$s_{ij} \equiv r_i \phi_j$

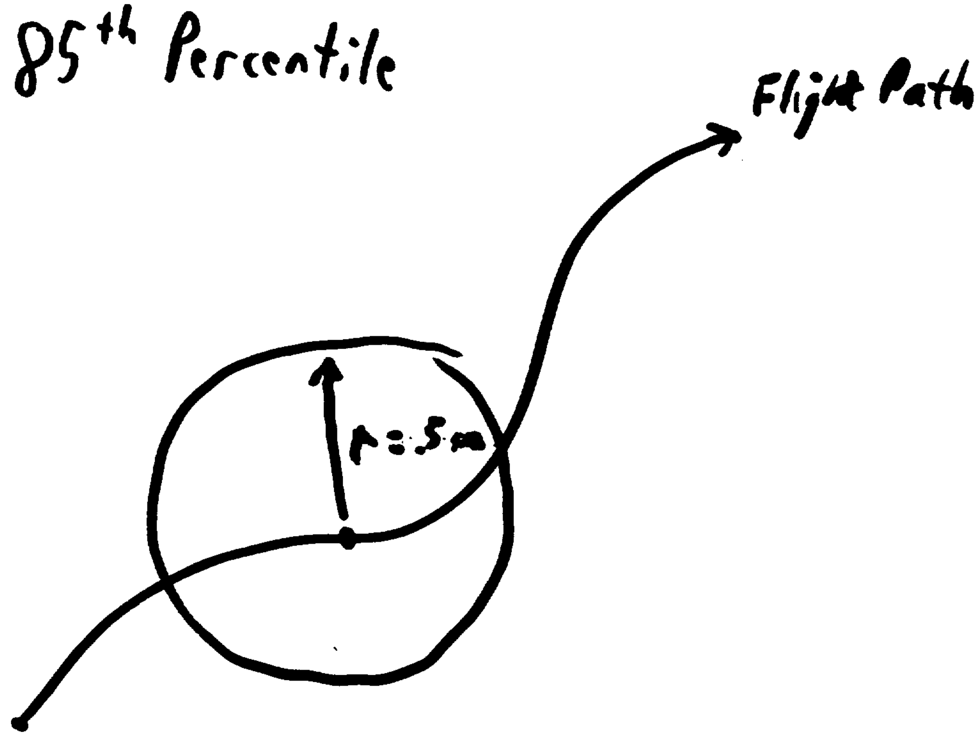
$r_i = r_0 + i\Delta r$

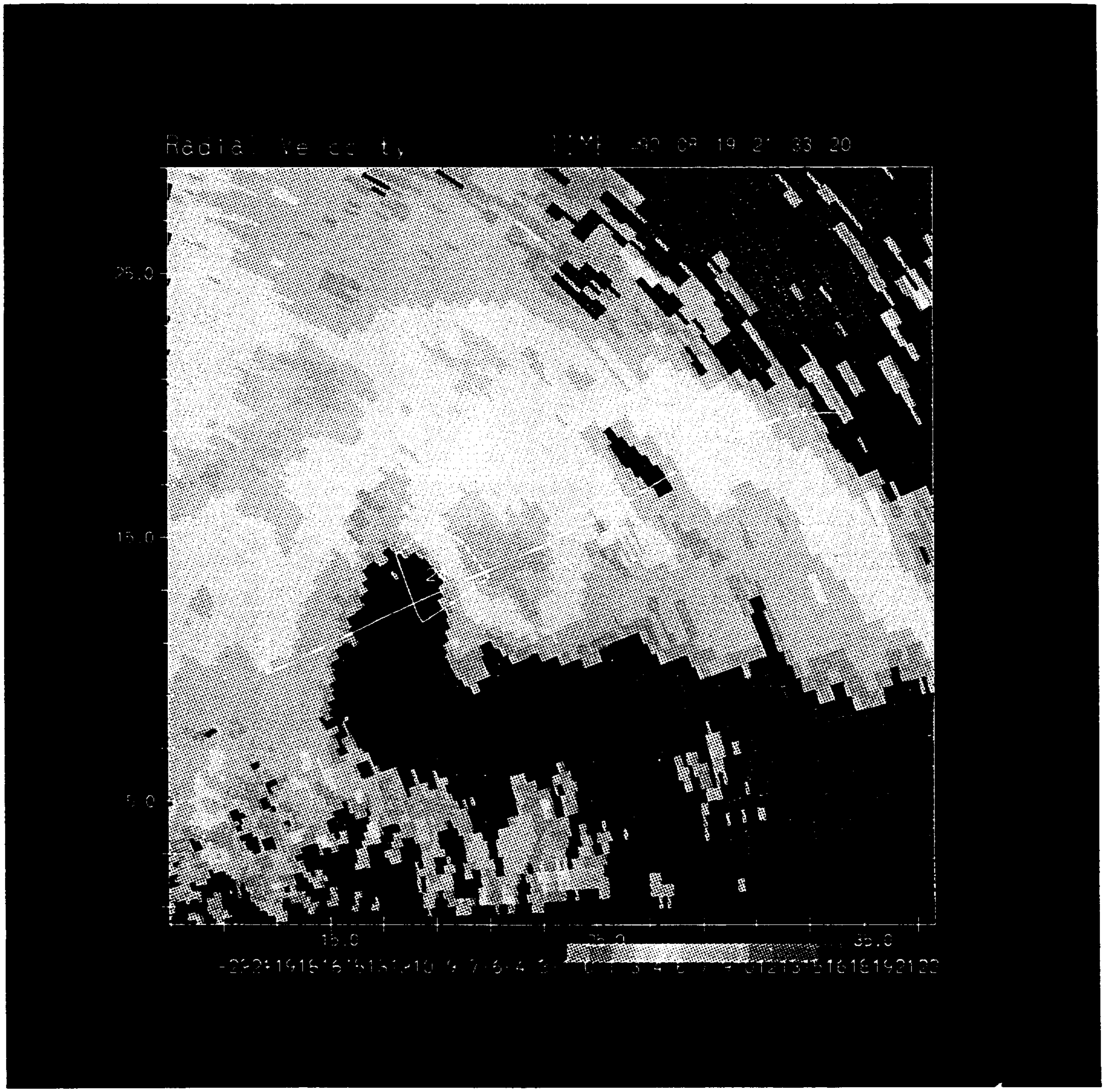
$\phi_j = j\Delta\phi$

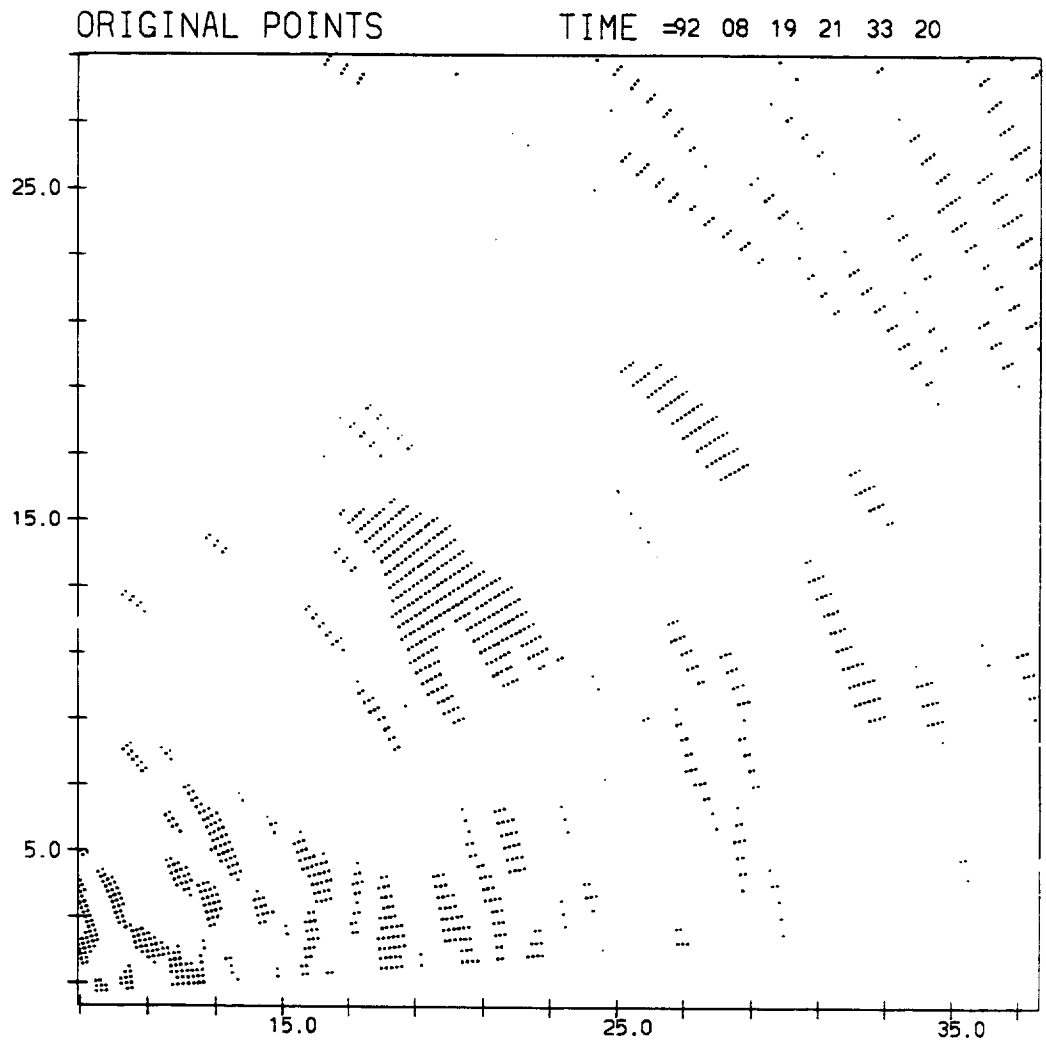
$u(r, \theta) \equiv$ radial velocity

fit locally

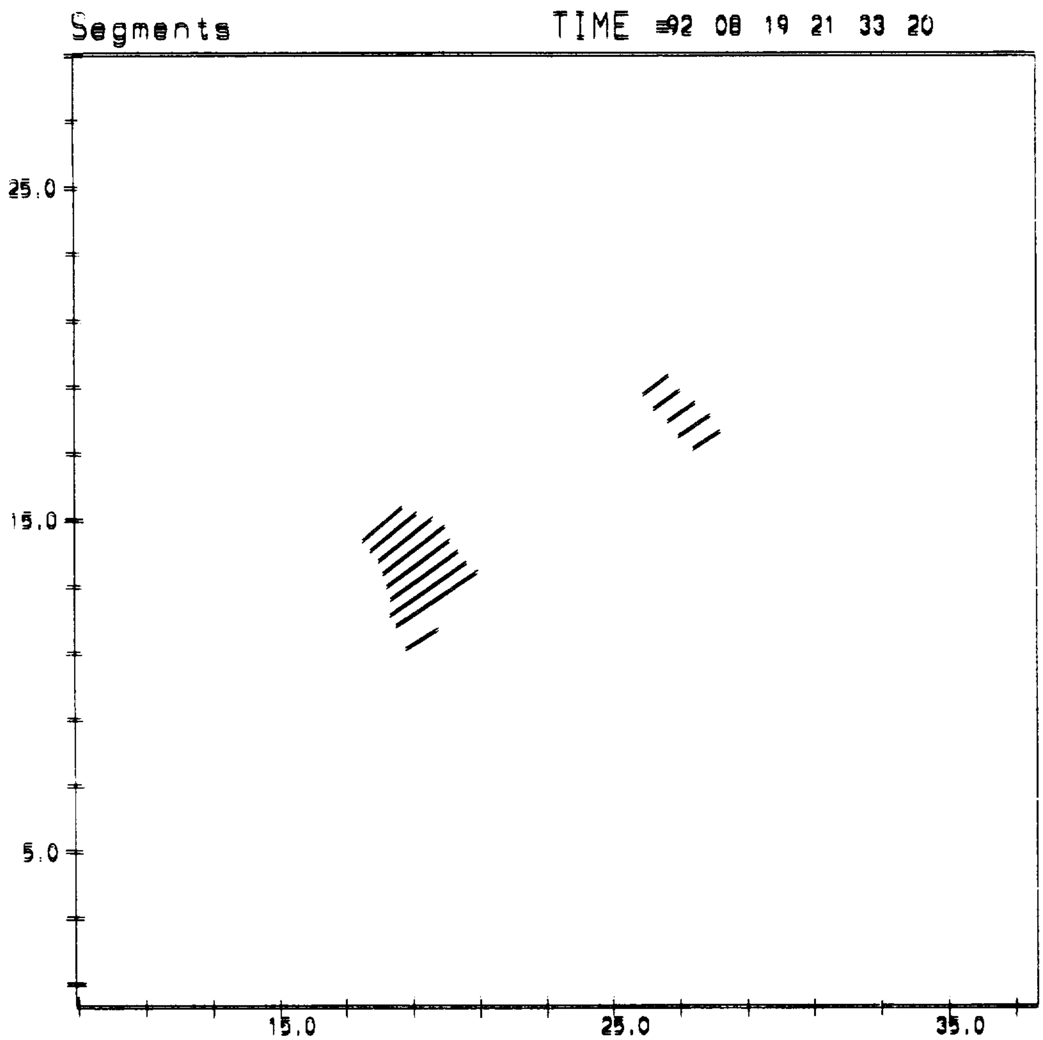
$\tilde{u}(r, s) = u_0 + u_r(r - r_0) + u_s(s - s_0)$


85th Percentile
Flight Path
r = 5m

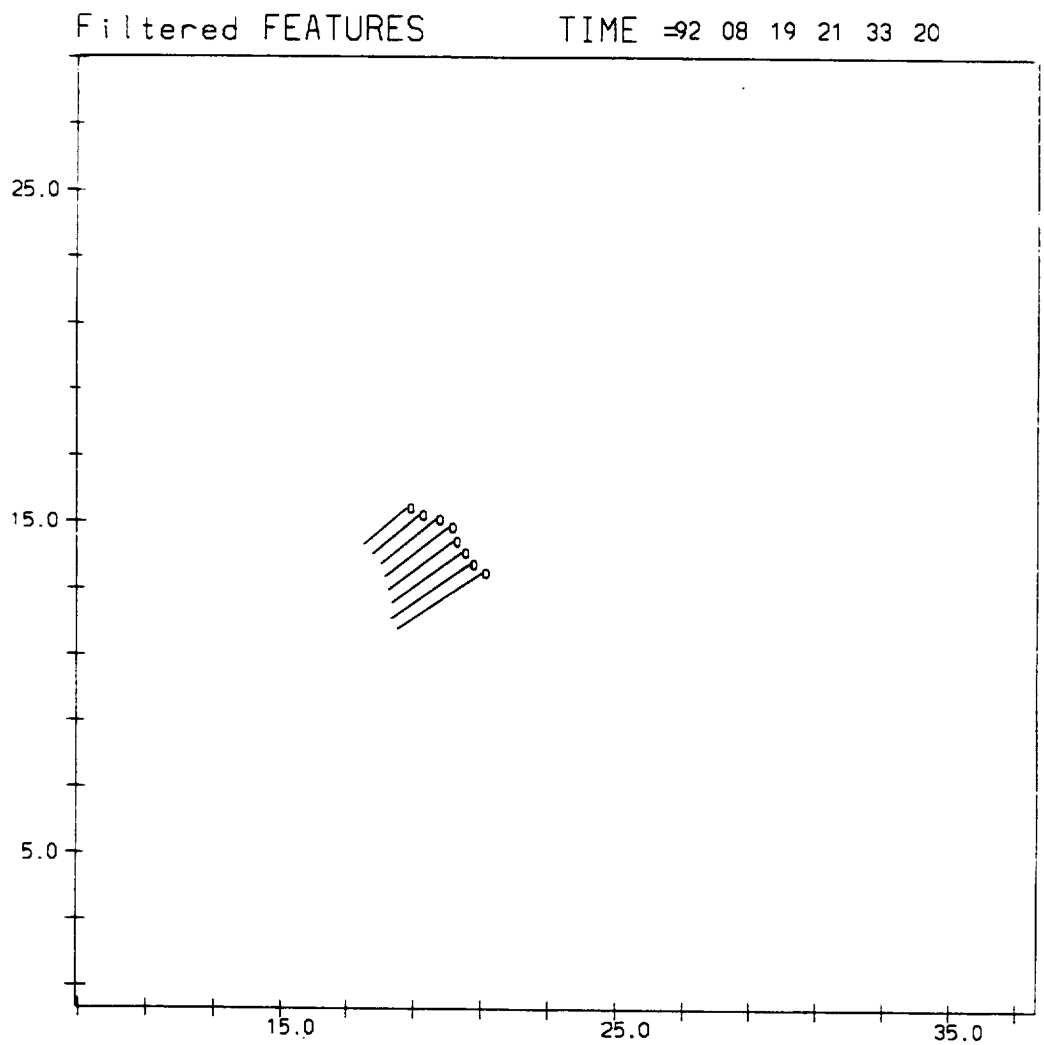

Radial Velocity
25.0
15.0
5.0
15.0
35.0



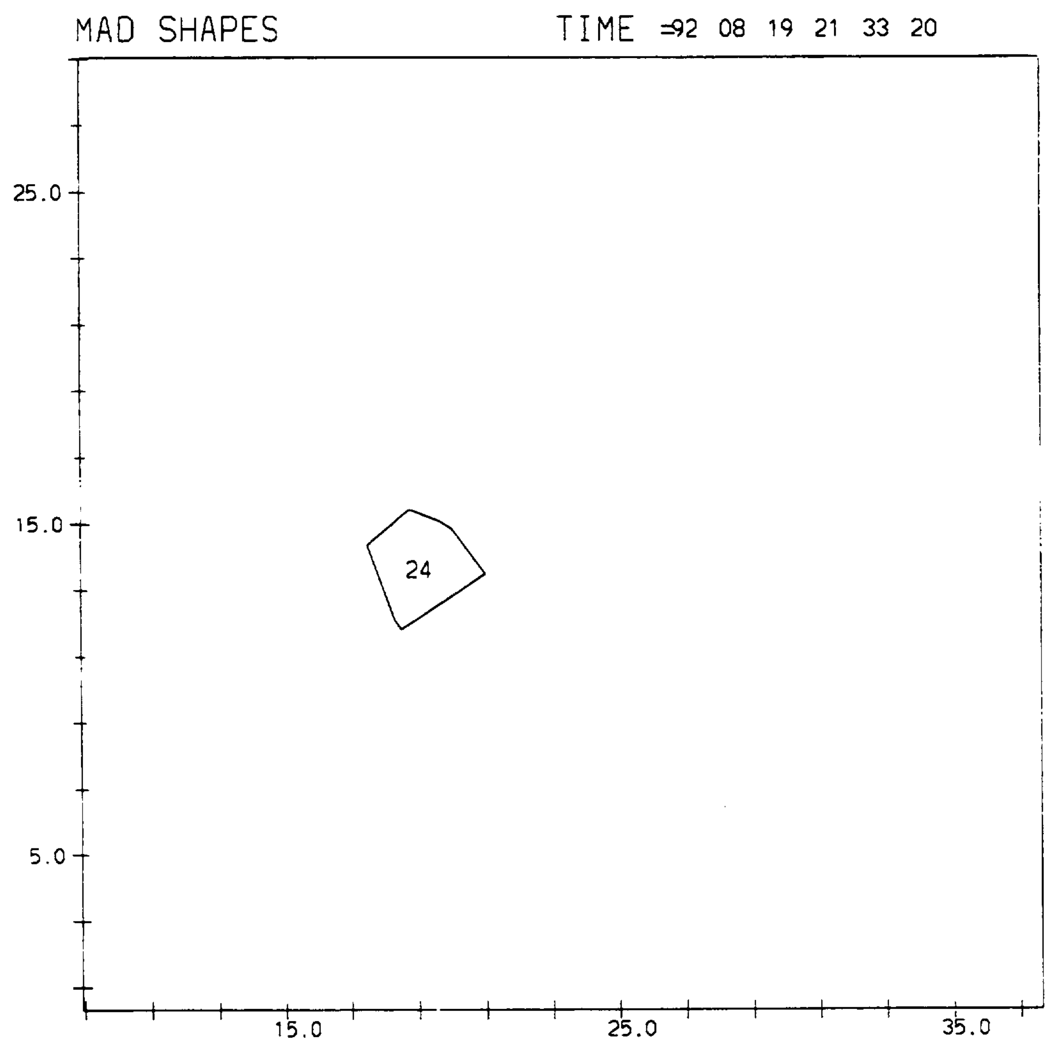
$u_r \geq .002$



Segments
TIME =92 08 19 21 33 20
25.0
15.0
5.0
15.0
25.0
35.0



Filtered FEATURES
TIME =92 08 19 21 33 20
25.0
15.0
5.0
15.0
25.0
35.0


MAD SHAPES
TIME =92 08 19 21 33 20
25.0
15.0
5.0
15.0
25.0
35.0
24

Factors Affecting Individual Path Correlations

Time differences between aircraft penetration and radar data collection.

Vertical mismatch between aircraft flight path and radar beam; aircraft either above or below the beam.

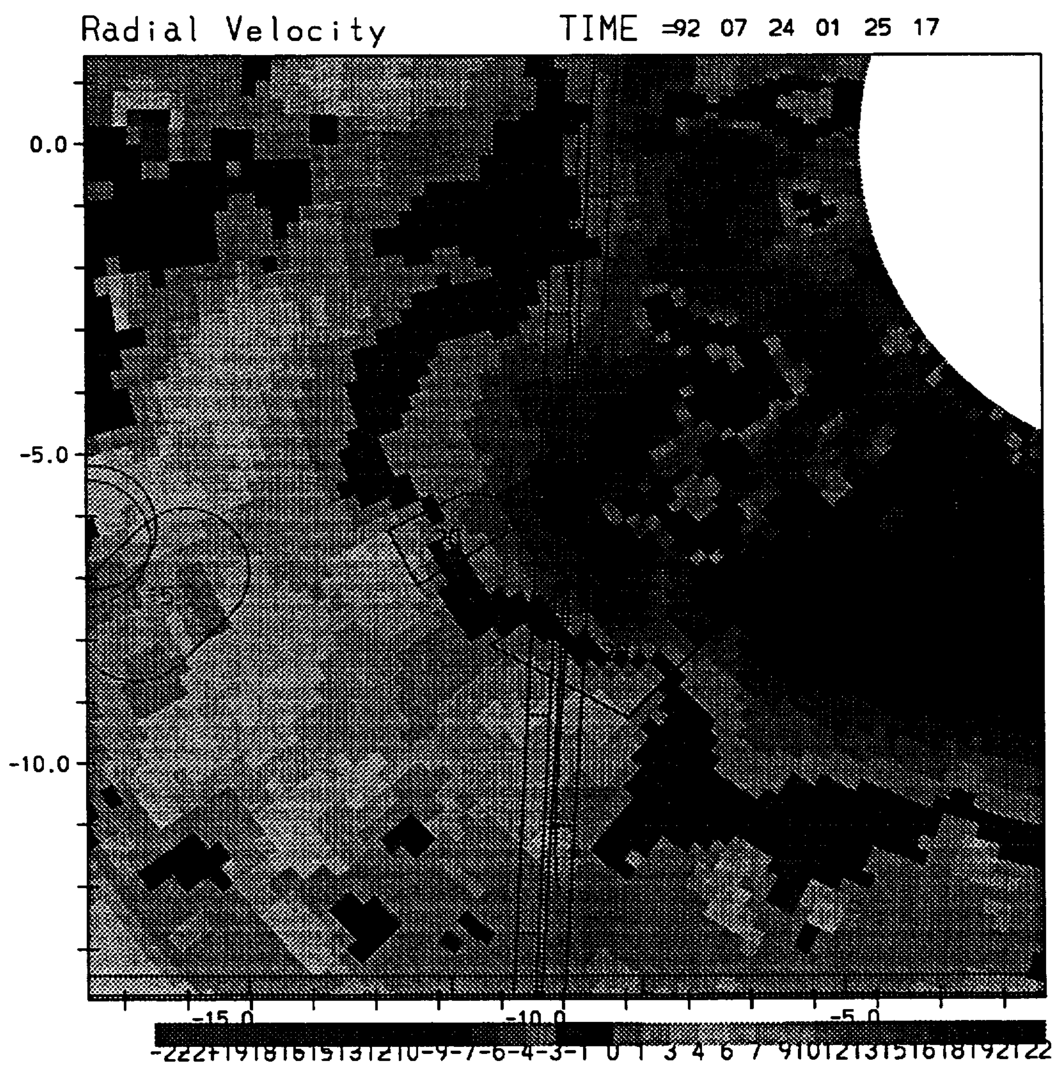
Aircraft distance from beam (too close or too far from radar).

Spatial resolution scale differences; the aircraft resolves smaller scales than the radar.

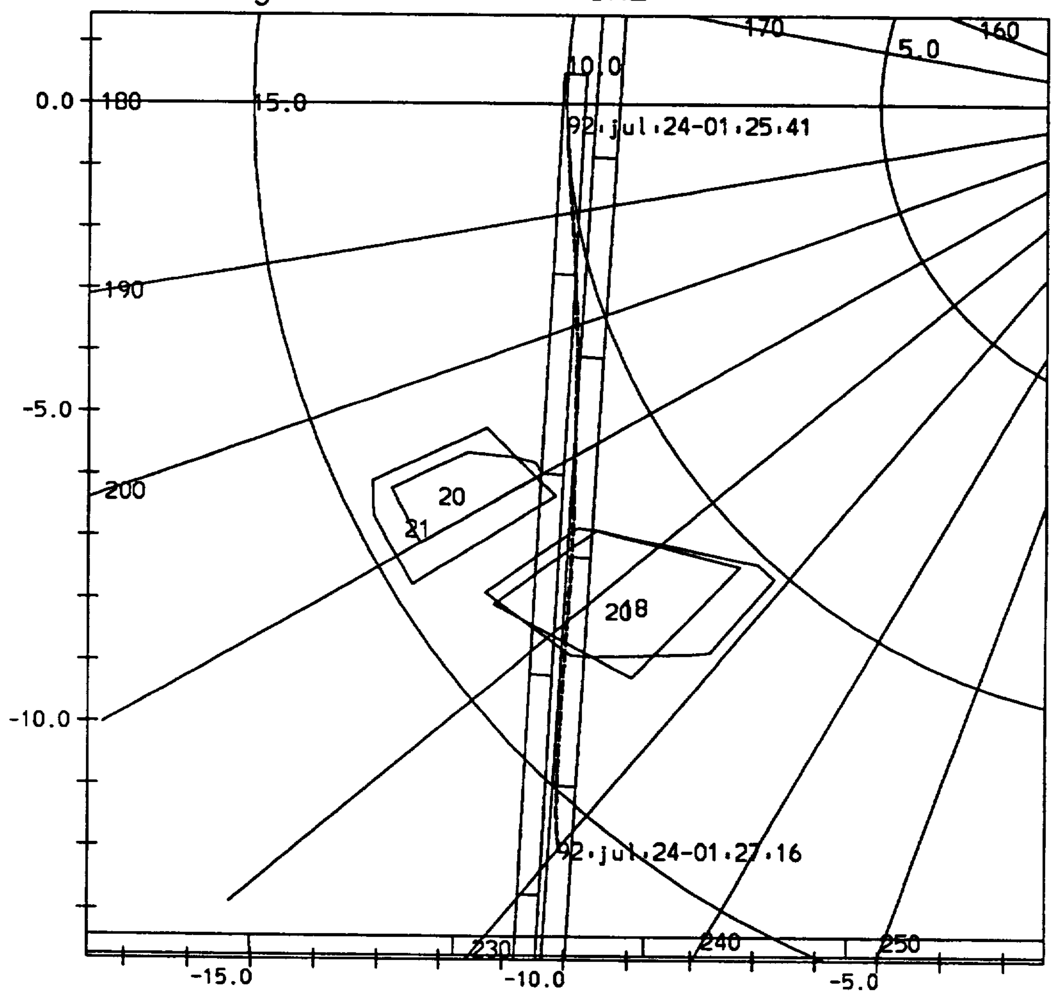
Inhomogeneous radar beam filling; scatterers may not be evenly distributed throughout the beam illumination volume.

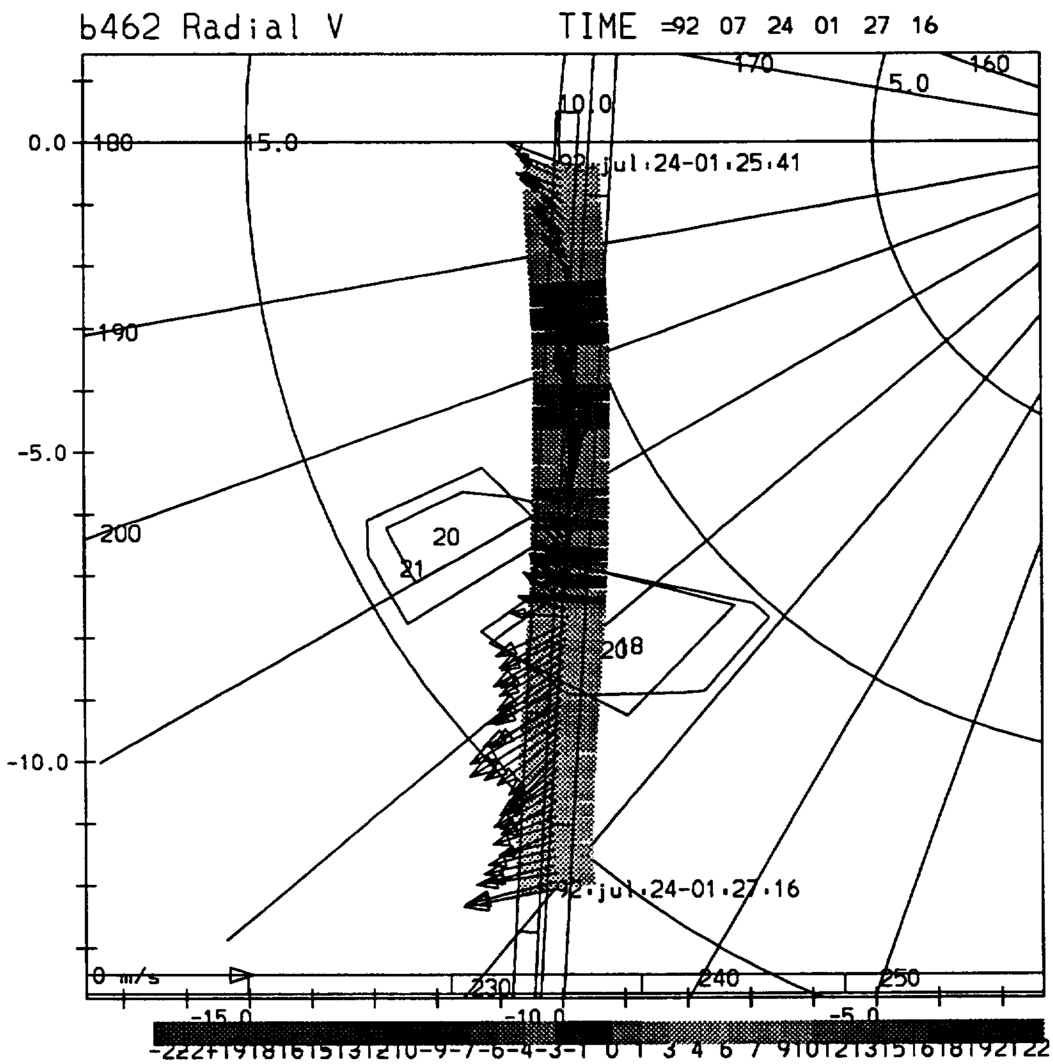
Small scale noise within radar data that eludes median filtering.

Phase lag between time and space of aircraft data due to low-pass filtering.

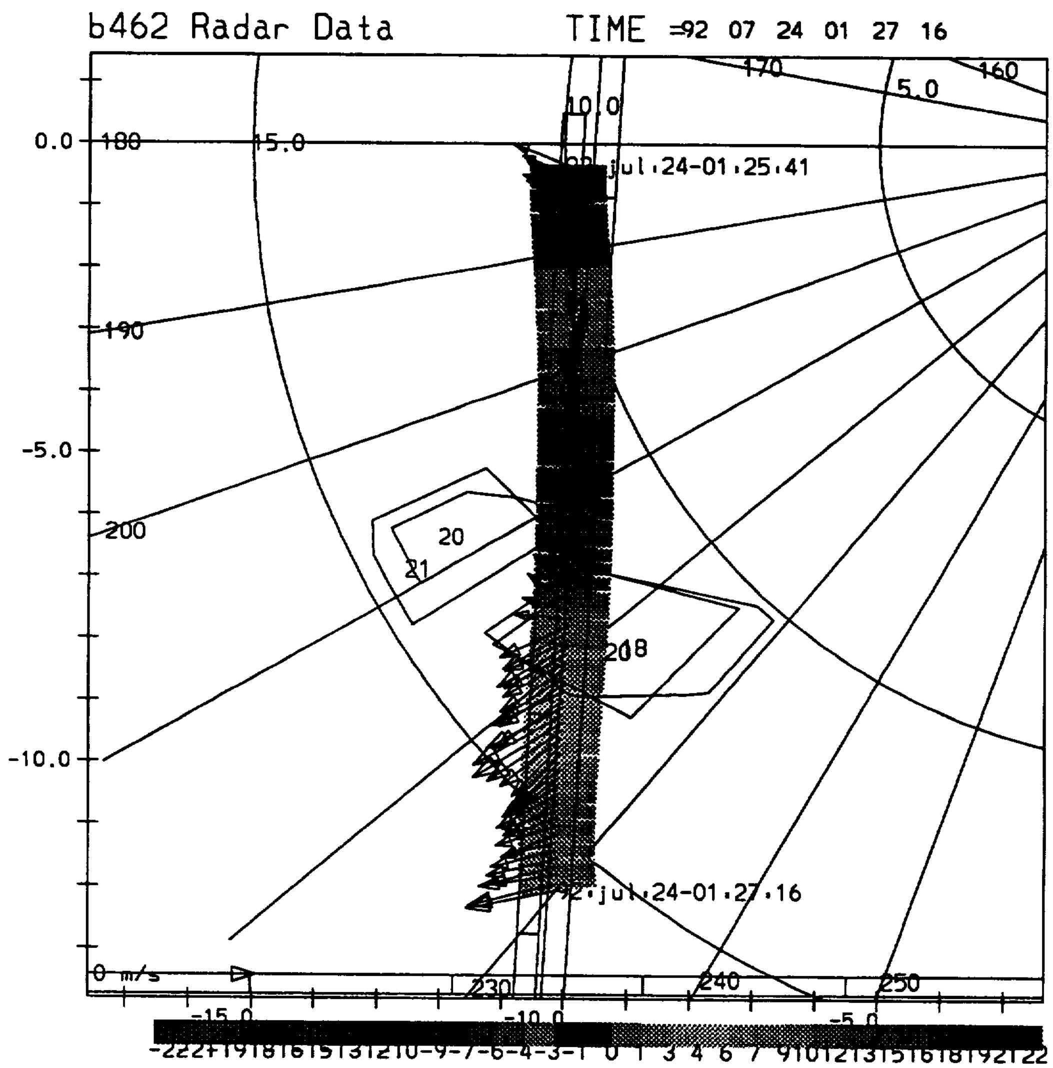

Radial Velocity
TIME =92 07 24 01 25 17
0.0
-5.0
-10.0
-15.0
-10.0
-5.0
0 1 3 4 6 7

b462 Flight Path TIME =92 07 24 01 27 16

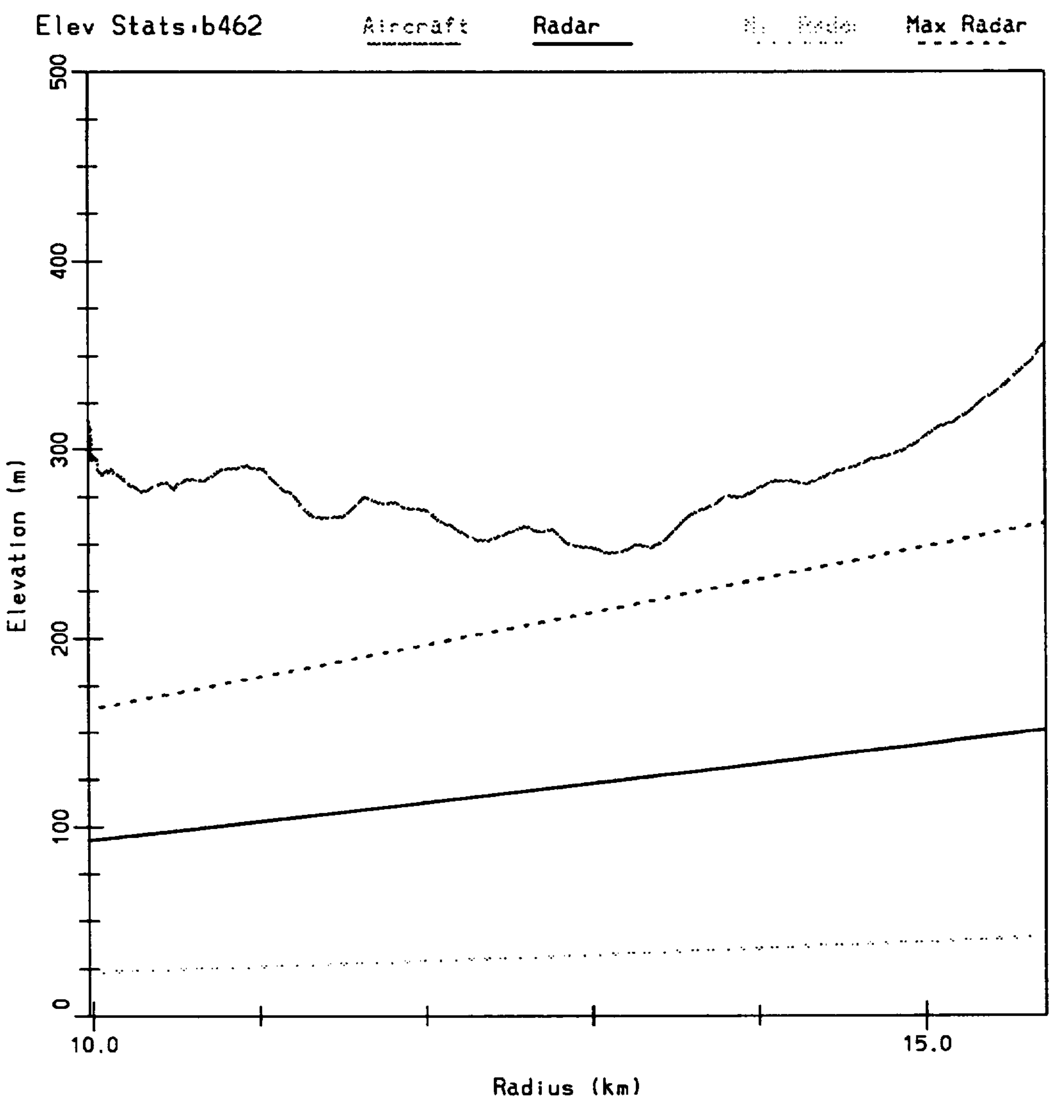


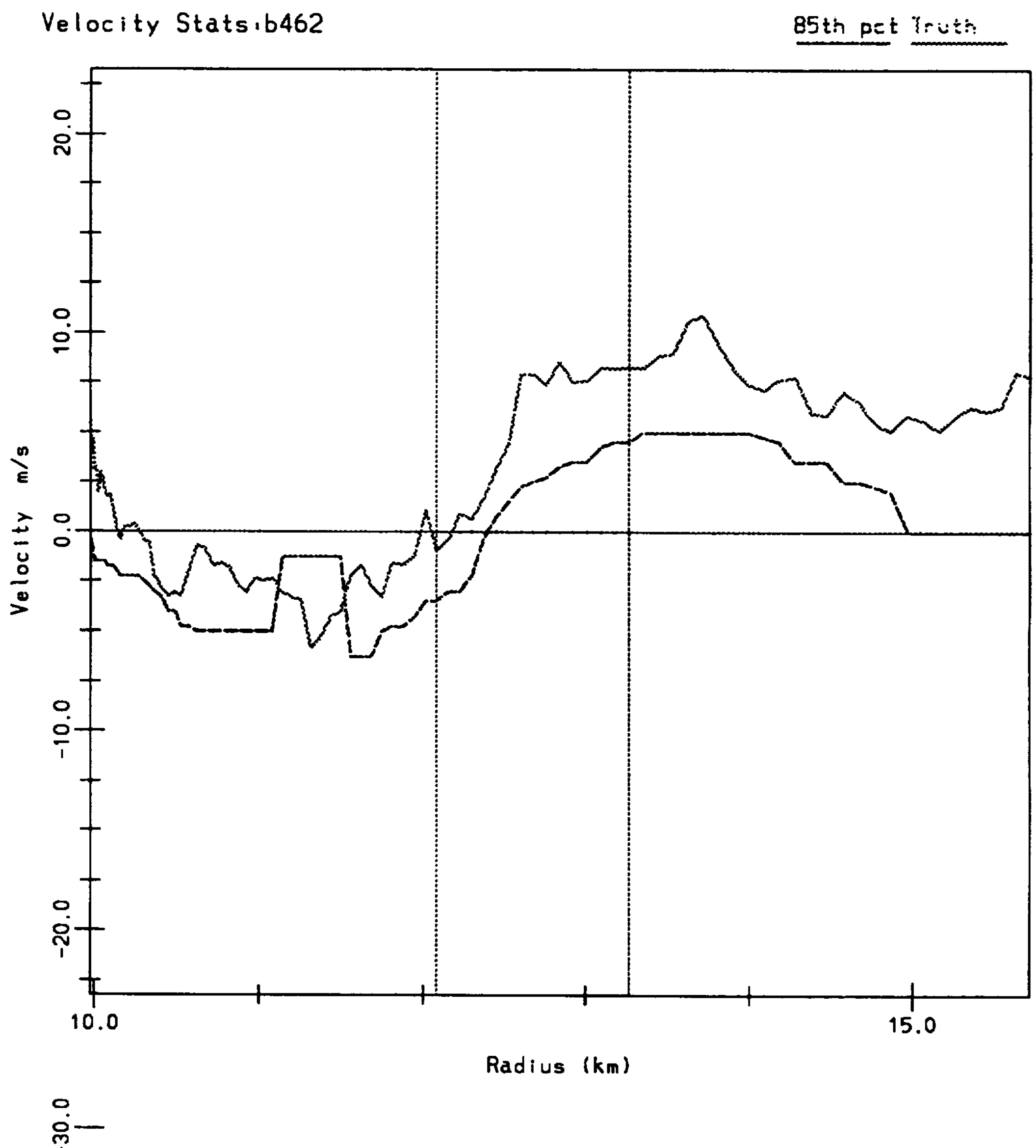


b462 Radial V
TIME =92 07 24 01 27 16
170
160
5.0
10.0
0.0
180
15.0
92.jul.24-01.25.41
190
-5.0
200
20
21
208
-10.0
92.jul.24-01.27.16
0 m/s
230
240
250
-15.0
-10.0
-5.0
-22 -21 -19 -18 -16 -15 -13 -12 -10 -9 -7 -6 -4 -3 -1 0 1 3 4 6 7 9 10 12 13 15 16 18 19 21 22

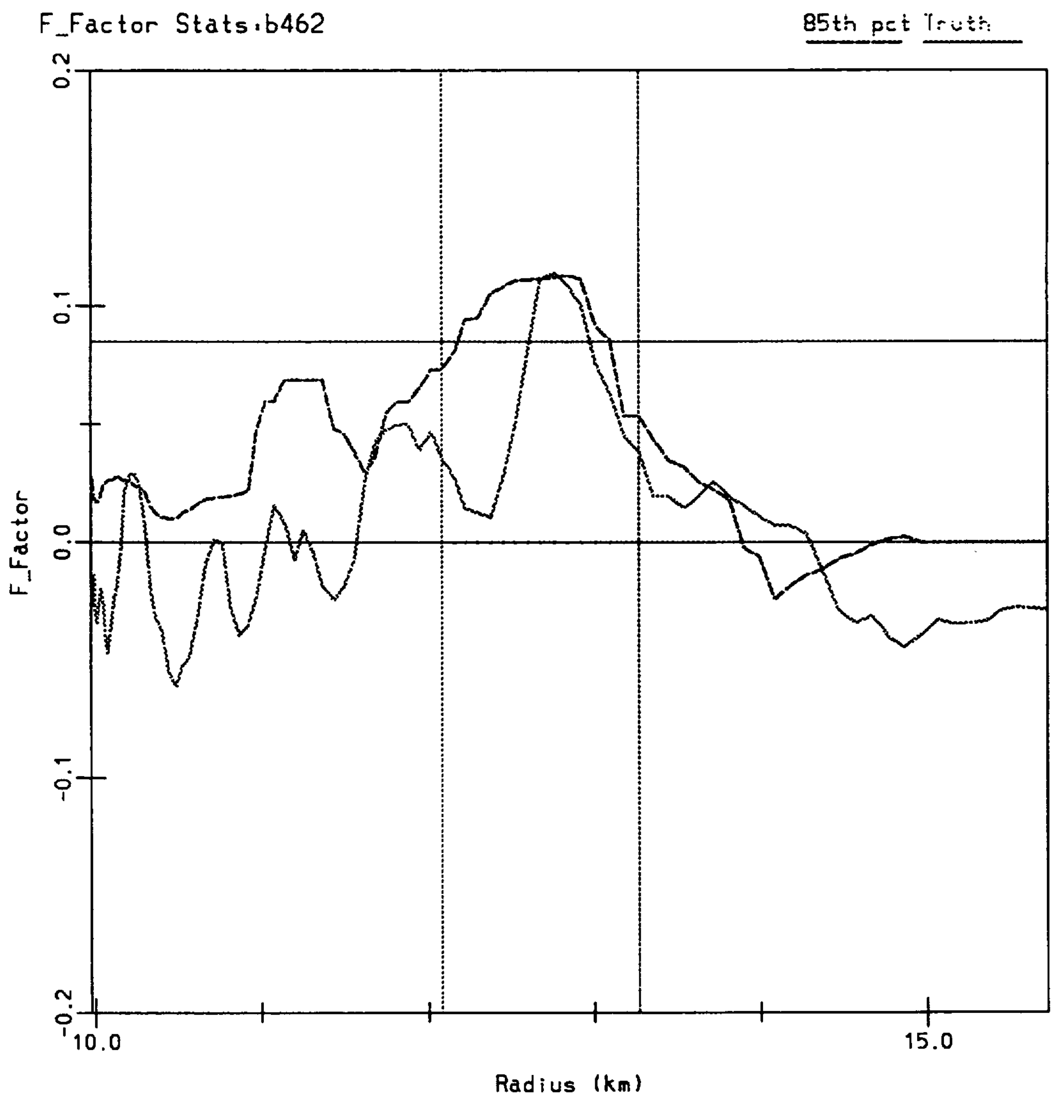


b462 Radar Data
TIME =92 07 24 01 27 16
0.0
-5.0
-10.0
180
190
200
170
160
230
240
250
15.0
10.0
5.0
-15.0
-10.0
-5.0
20
21
18
0 m/s
92 jul 24-01 25 41
92 jul 24-01 27 16

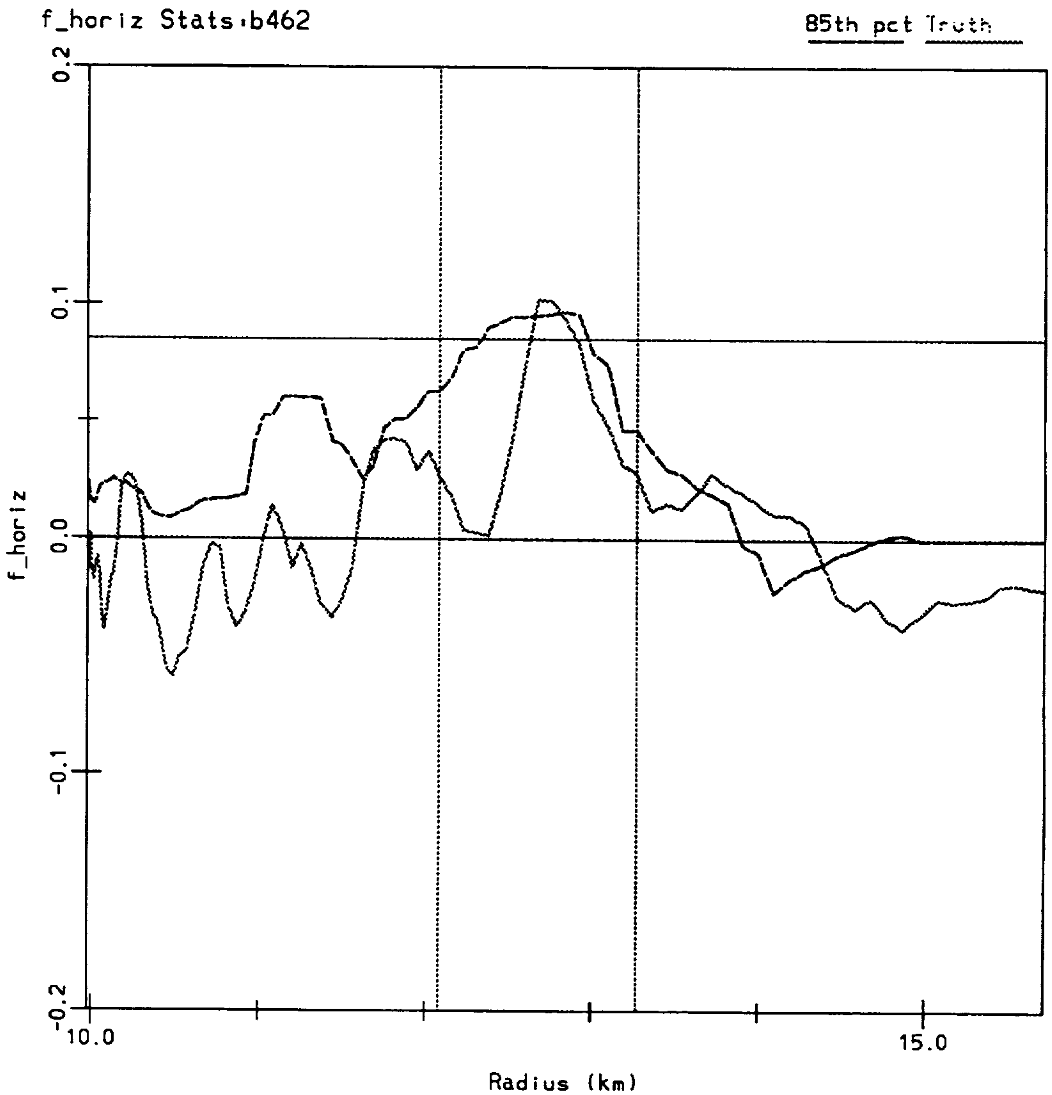

Elev Stats:b462
Aircraft
Radar
Max Radar
Elevation (m)
0
100
200
300
400
500
10.0
15.0
Radius (km)

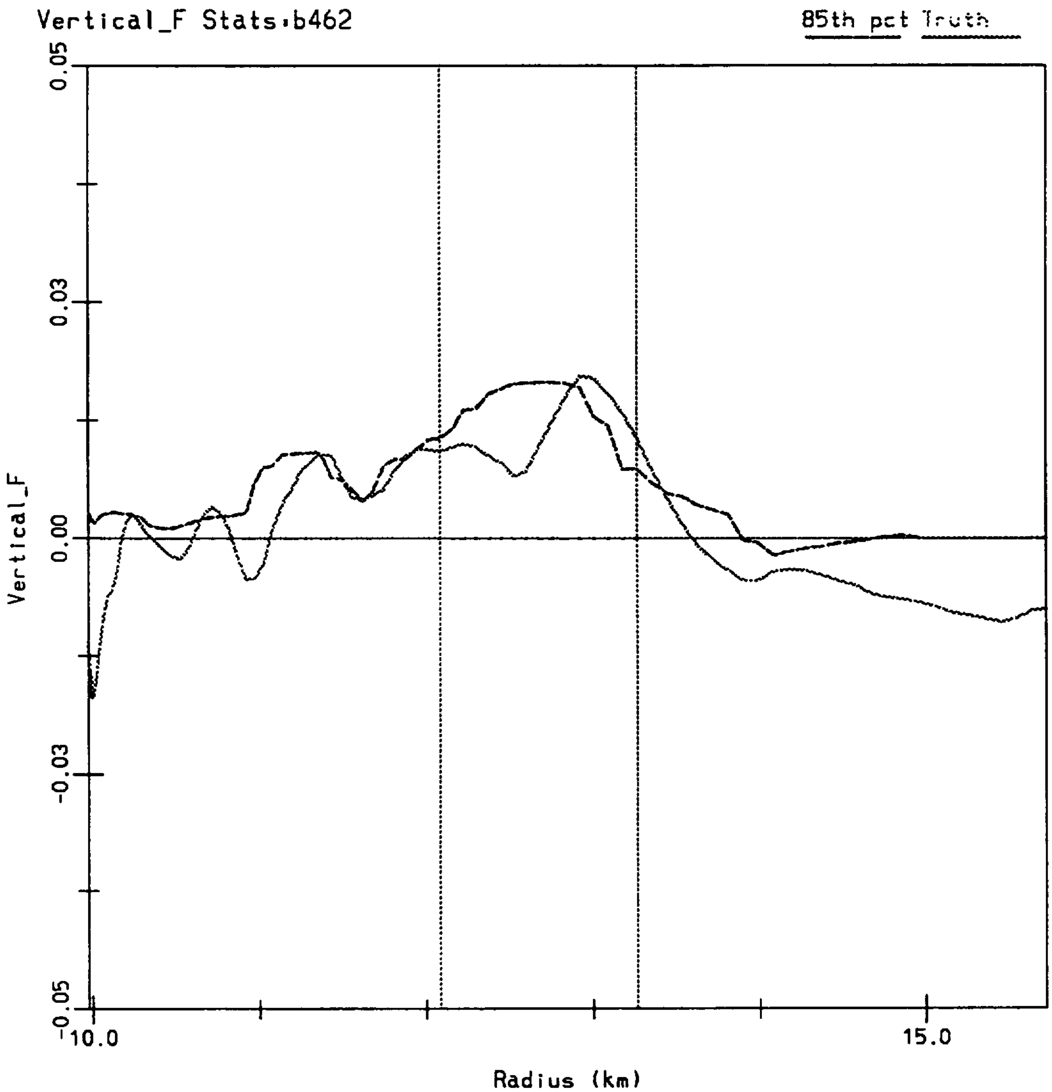


Velocity Stats:b462
85th pct Truth
20.0
10.0
0.0
-10.0
-20.0
-30.0
Velocity m/s
10.0
15.0
Radius (km)

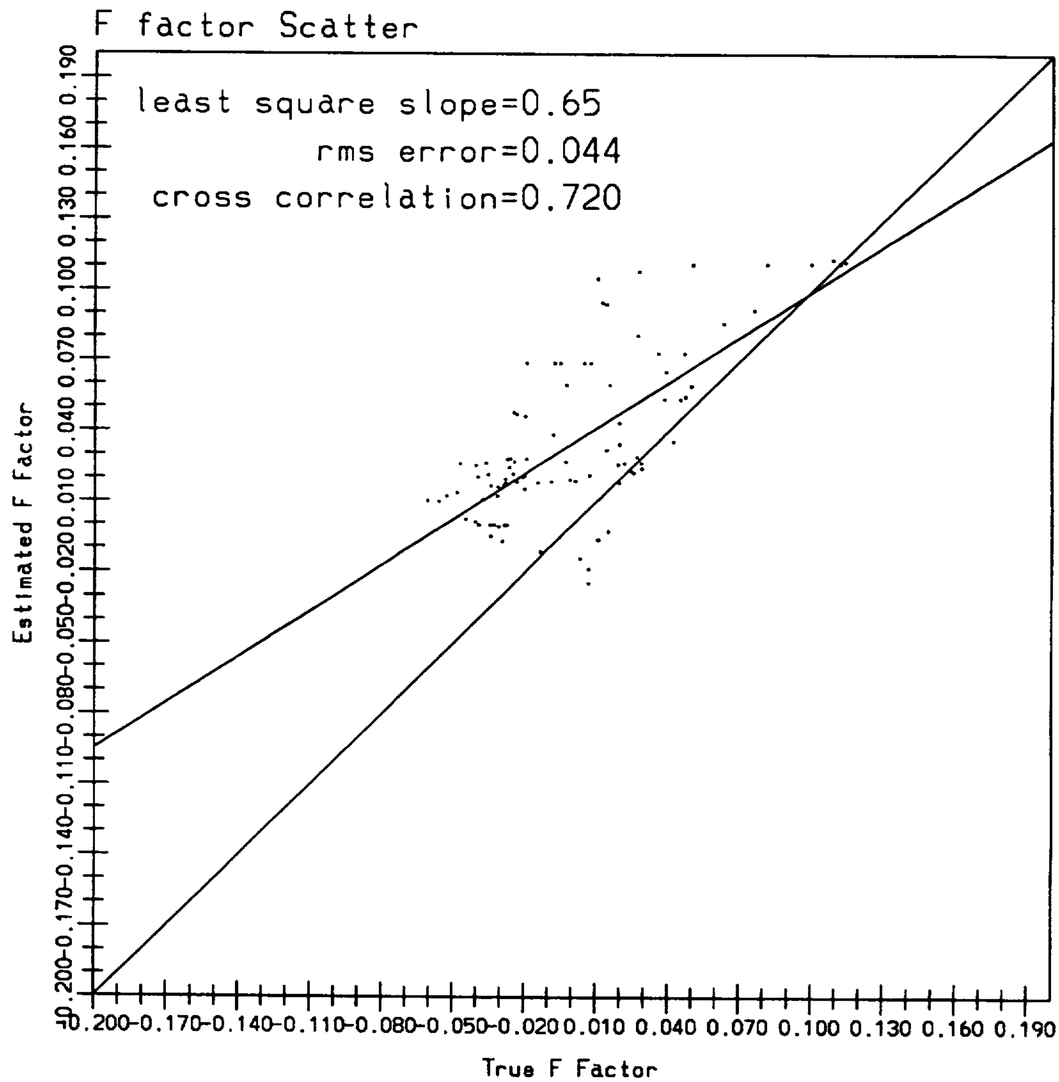


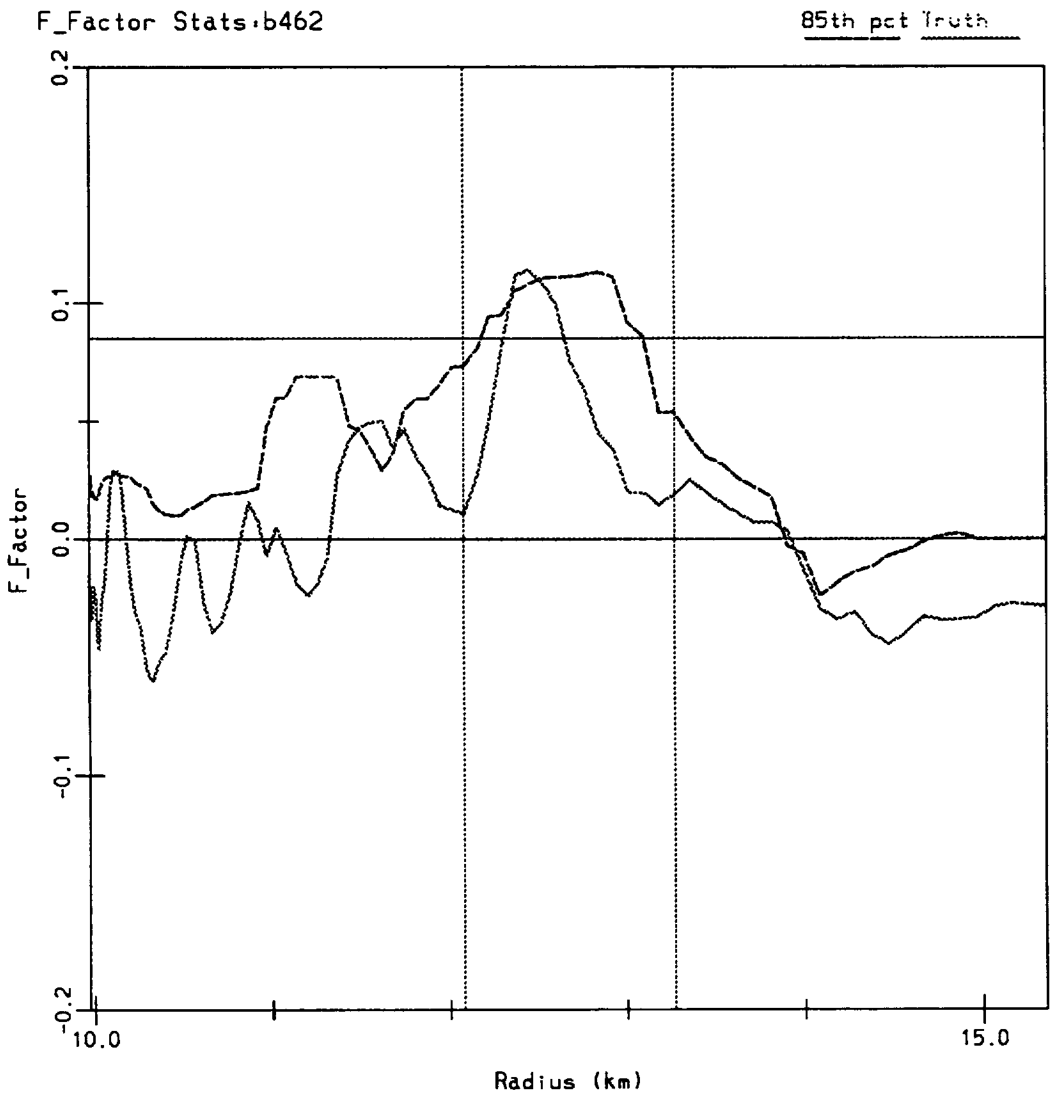
F_Factor Stats:b462
85th pct Truth
0.2
0.1
0.0
-0.1
-0.2
F_Factor
10.0
15.0
Radius (km)

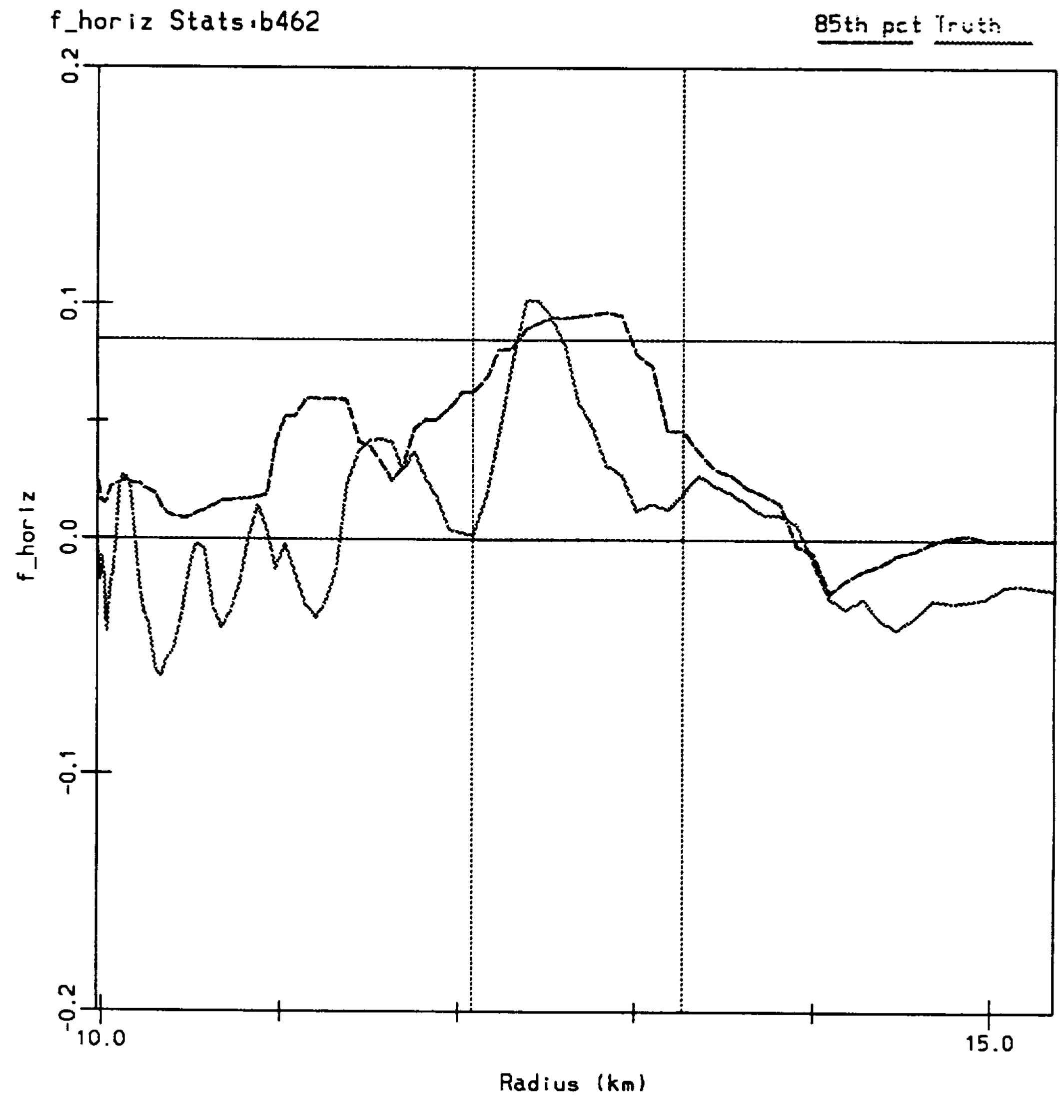

f_horiz Stats:b462
85th pct Truth
0.2
0.1
0.0
-0.1
-0.2
f_horiz
10.0
15.0
Radius (km)

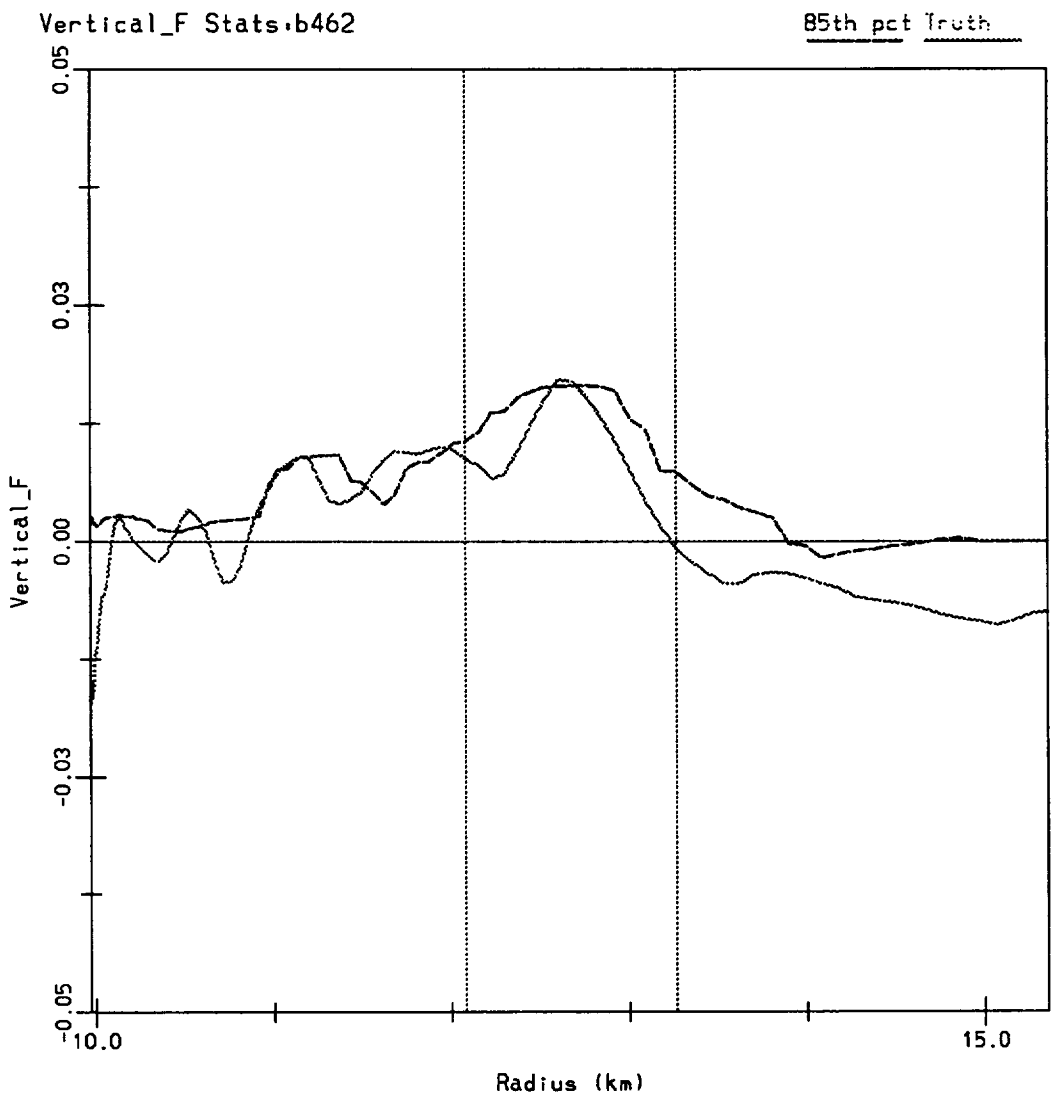


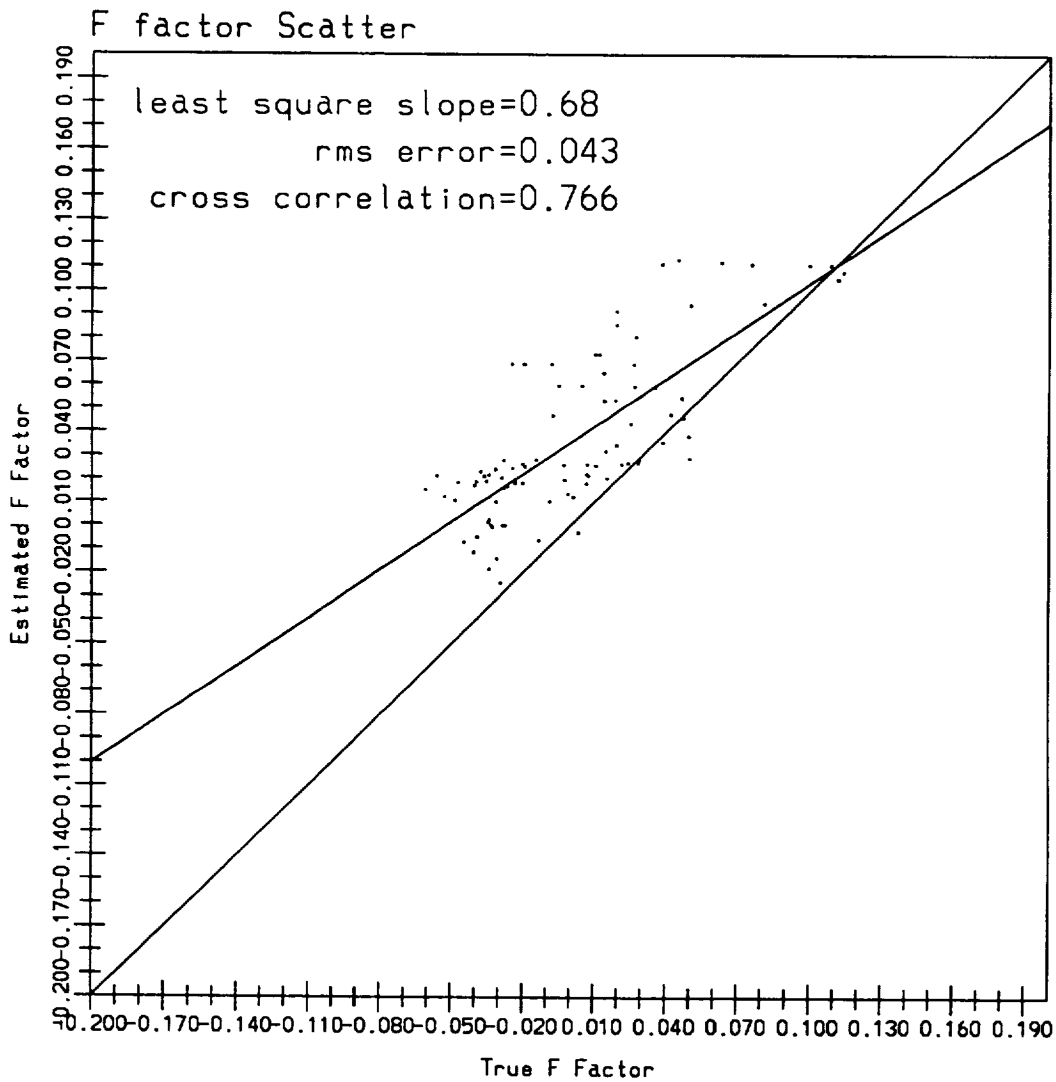
Vertical_F Stats:b462
85th pct Truth
0.05
0.03
0.00
-0.03
-0.05
Vertical_F
10.0
15.0
Radius (km)


F factor Scatter
least square slope=0.65
rms error=0.044
cross correlation=0.720
Estimated F Factor
-0.200-0.170-0.140-0.110-0.080-0.050-0.020 0.010 0.040 0.070 0.100 0.130 0.160 0.190
-0.200-0.170-0.140-0.110-0.080-0.050-0.020 0.010 0.040 0.070 0.100 0.130 0.160 0.190
True F Factor

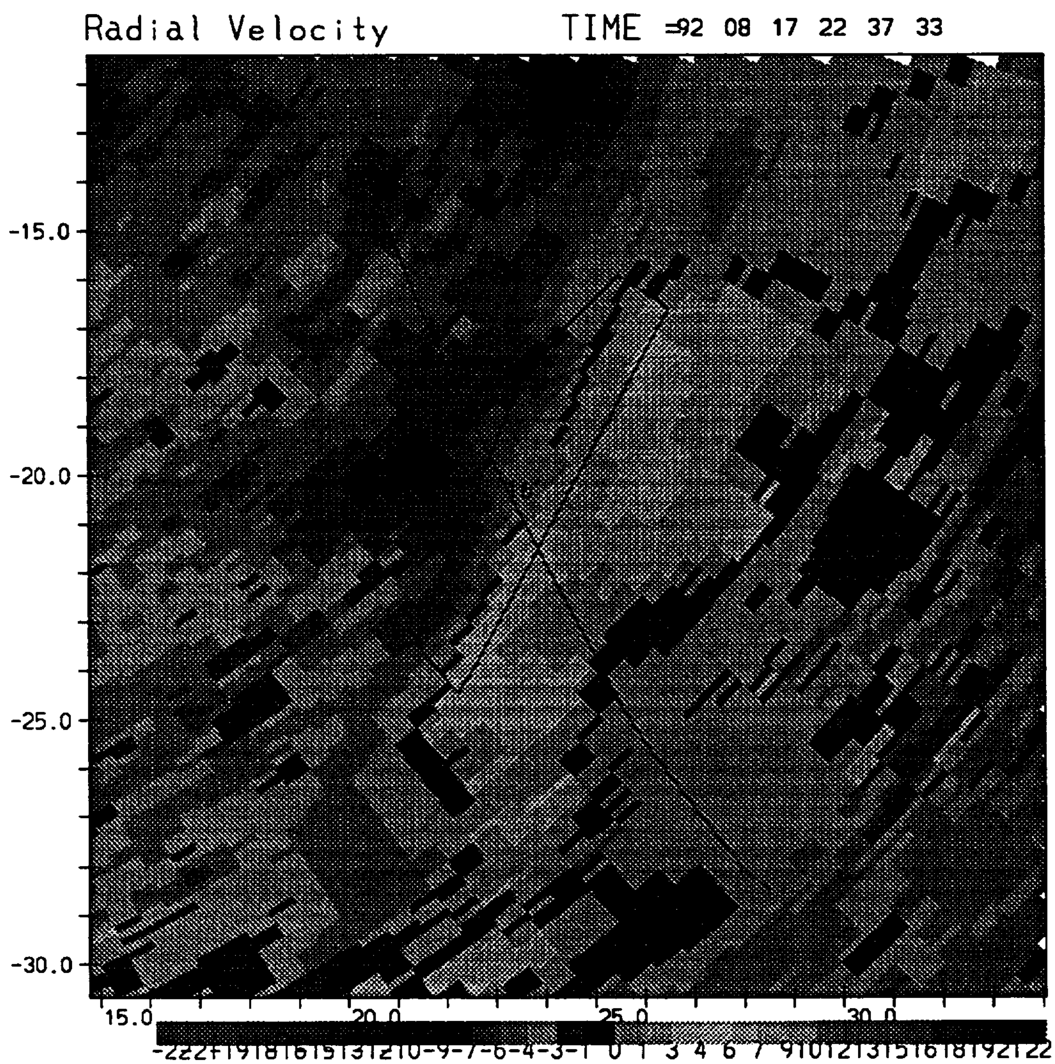

F_Factor Stats:b462
85th pct Truth
0.2
0.1
0.0
-0.1
-0.2
F_Factor
10.0
15.0
Radius (km)

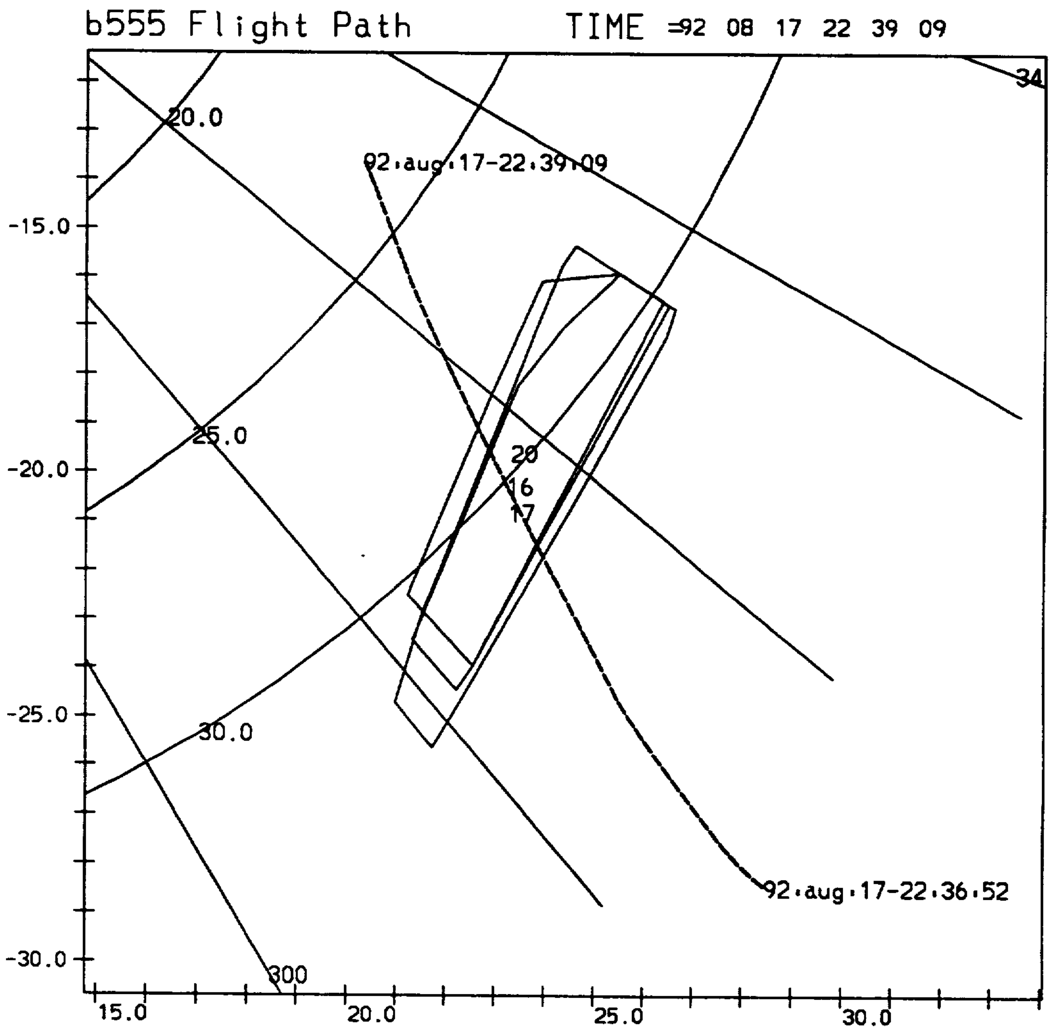

f_horiz Stats:b462
85th pct Truth
0.2
0.1
0.0
-0.1
-0.2
f_horiz
10.0
15.0
Radius (km)

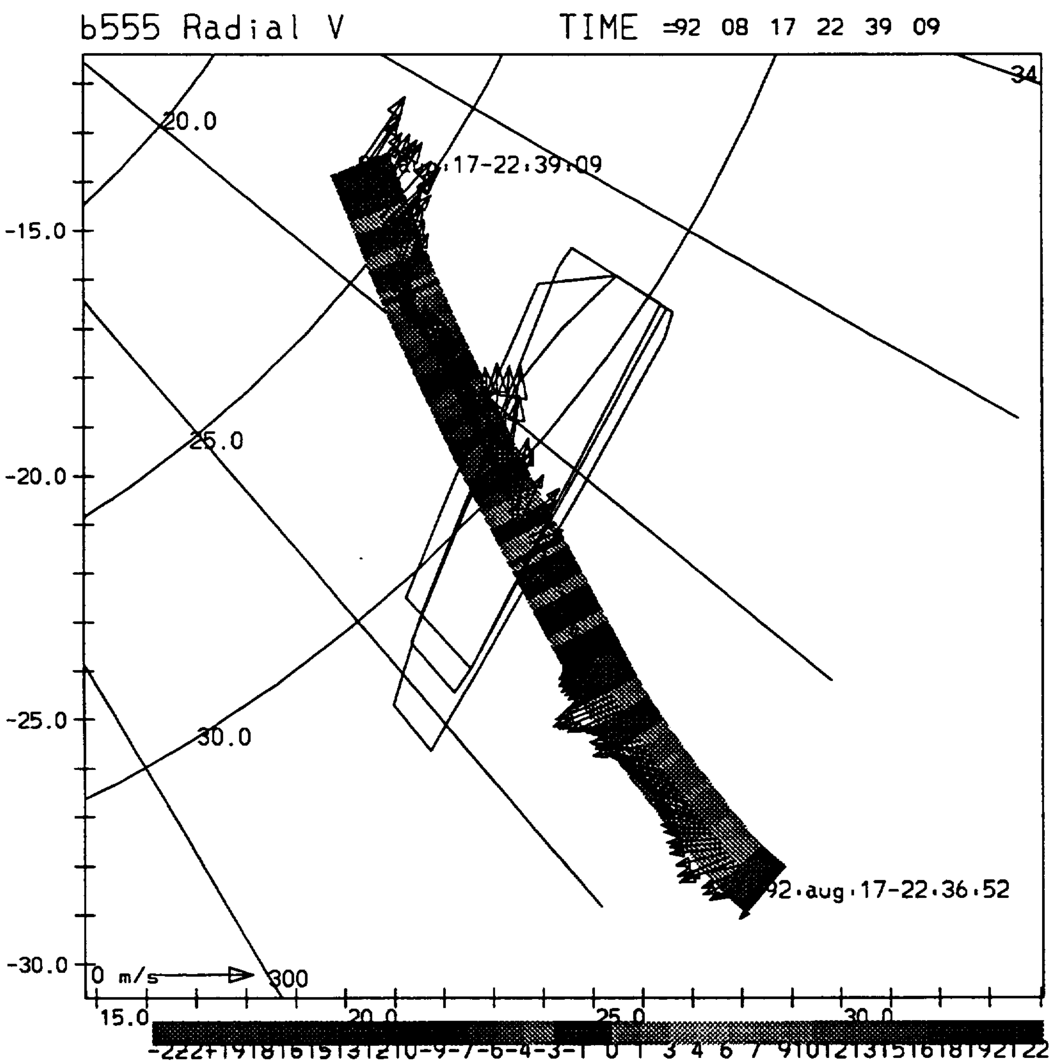

Vertical_F Stats.b462
85th pct Truth
0.05
0.03
0.00
-0.03
-0.05
Vertical_F
10.0
15.0
Radius (km)

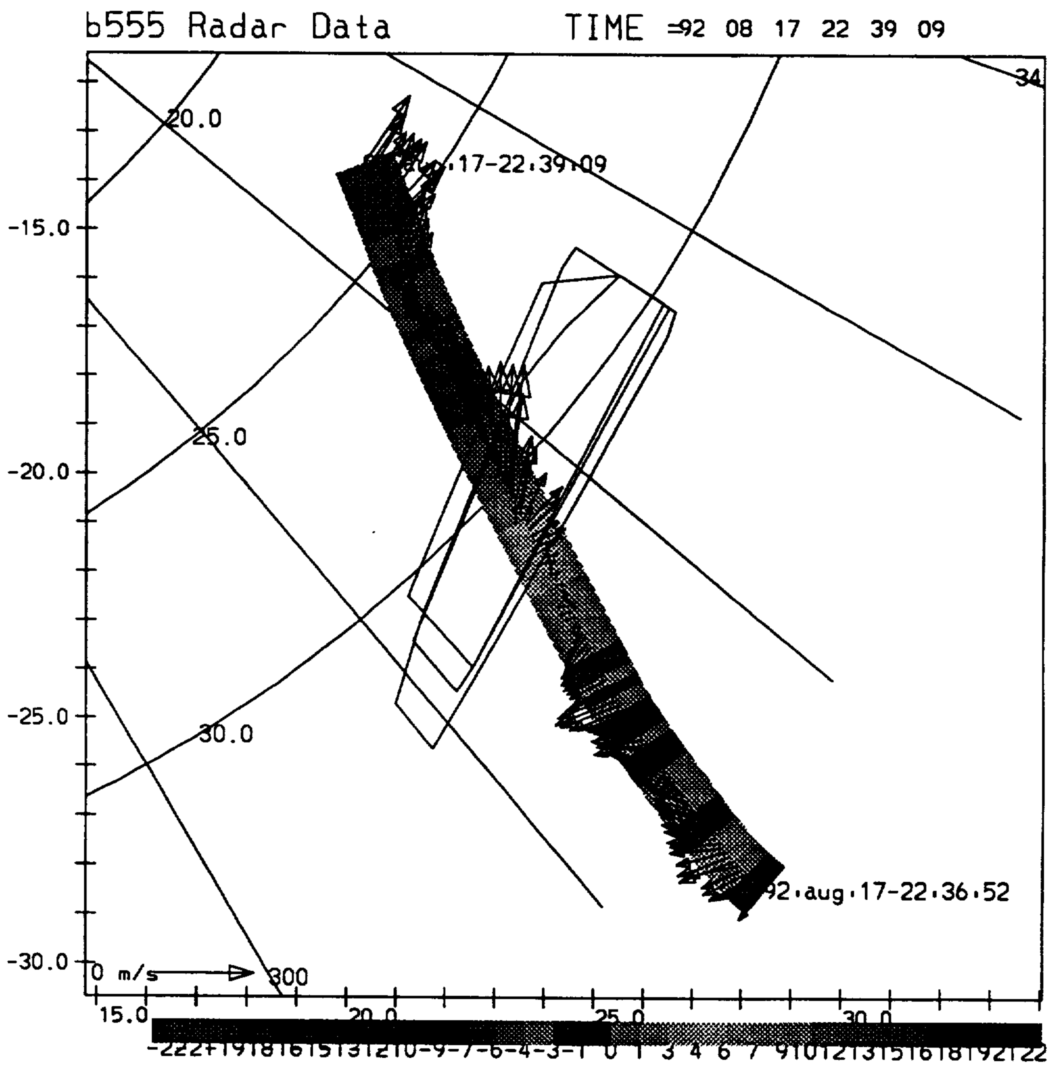


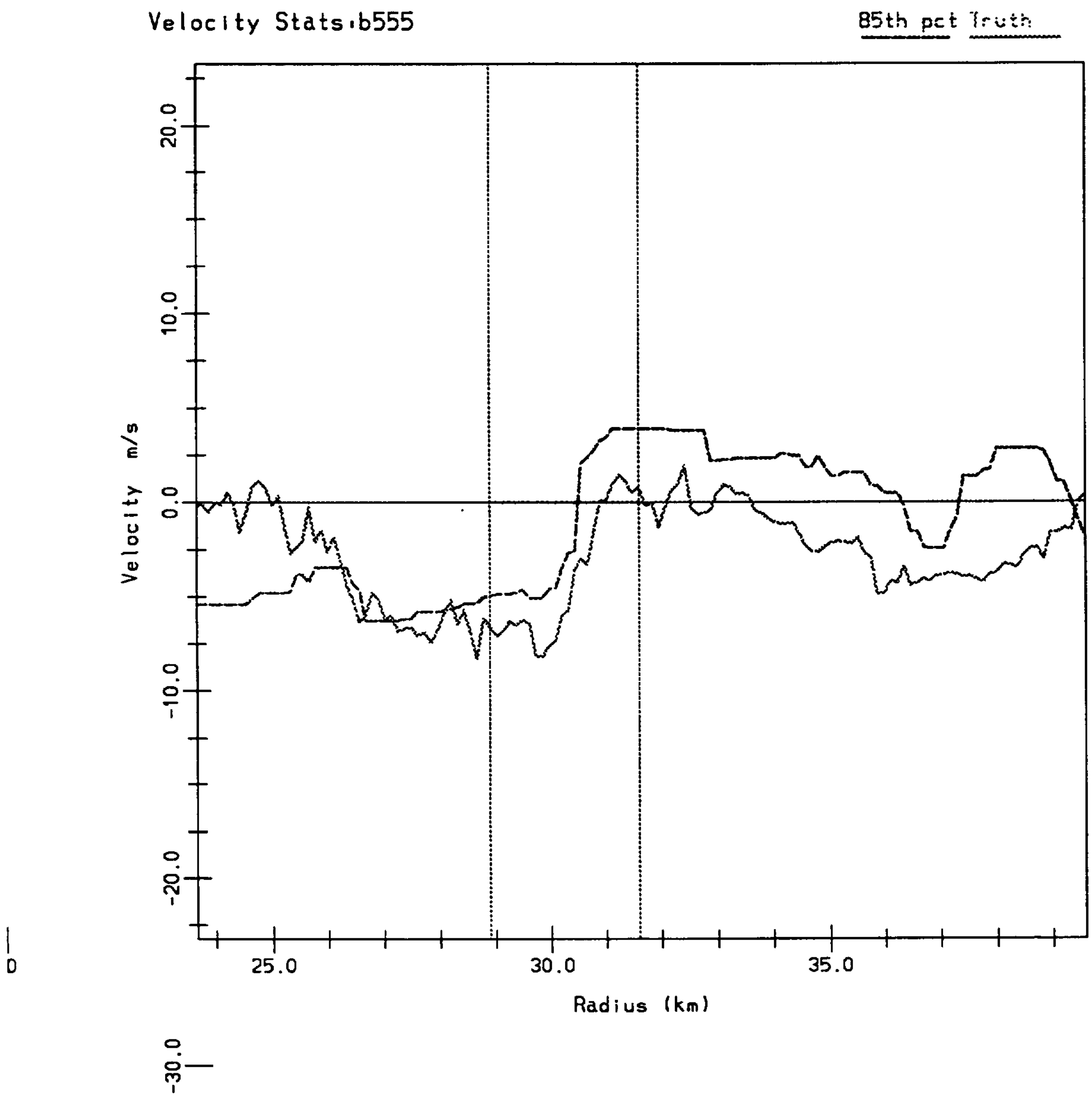
F factor Scatter
least square slope=0.68
rms error=0.043
cross correlation=0.766
Estimated F Factor
-0.200-0.170-0.140-0.110-0.080-0.050-0.020 0.010 0.040 0.070 0.100 0.130 0.160 0.190
-0.200-0.170-0.140-0.110-0.080-0.050-0.020 0.010 0.040 0.070 0.100 0.130 0.160 0.190
True F Factor

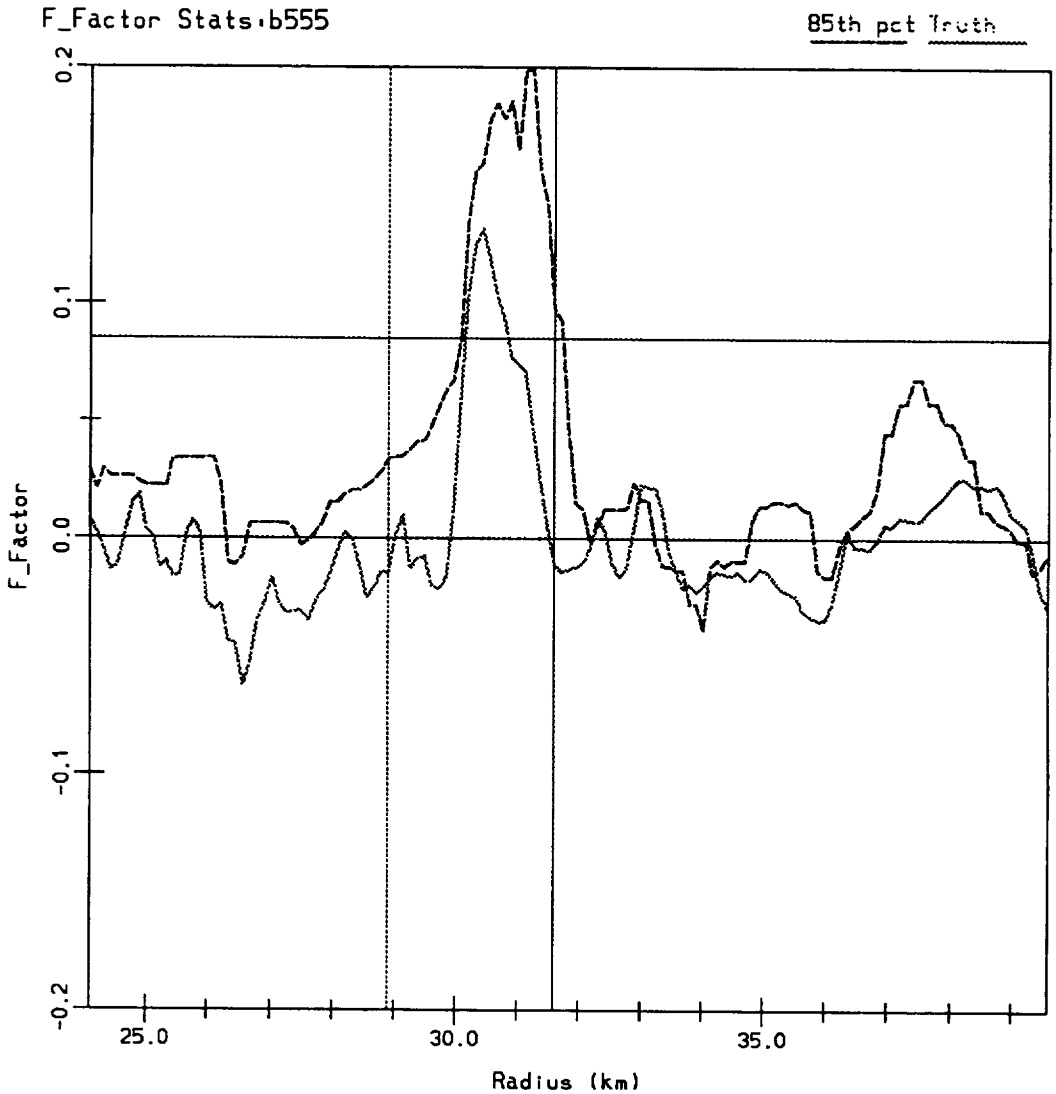

Radial Velocity
TIME =92 08 17 22 37 33
-15.0
-20.0
-25.0
-30.0
15.0
20.0
25.0
30.0
-9 -7 -6 -4 -3 -1 0 1 3 4 6 7

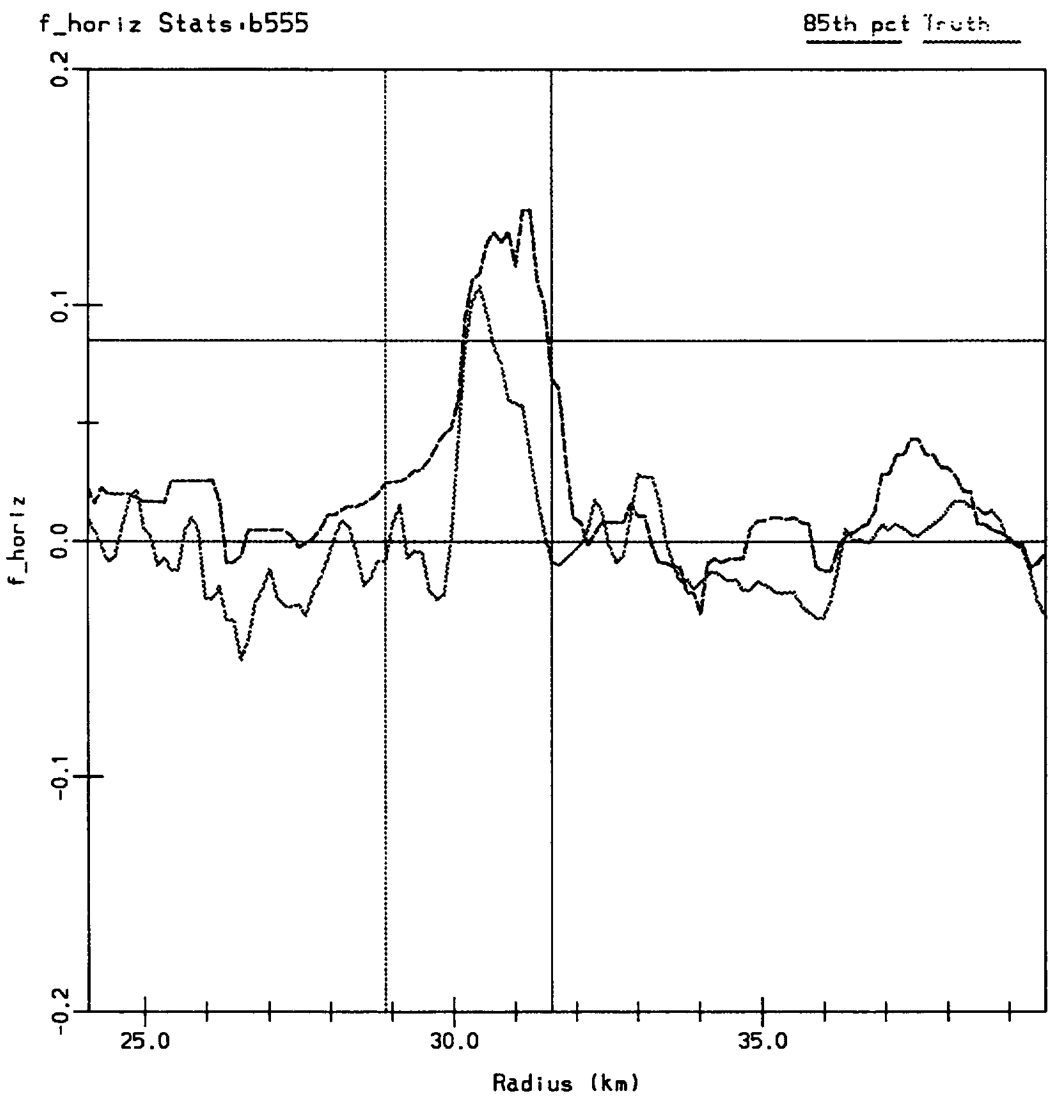

b555 Flight Path
TIME =92 08 17 22 39 09
20.0
25.0
30.0
300
34
92.aug.17-22.39.09
92.aug.17-22.36.52
20
16
17
-15.0
-20.0
-25.0
-30.0
15.0
20.0
25.0
30.0


b555 Radial V
TIME =92 08 17 22 39 09
20.0
25.0
30.0
34
-15.0
-20.0
-25.0
-30.0
15.0
20.0
25.0
30.0
0 m/s
300
17-22:39:09
92:aug:17-22:36:52
-22 21 19 18 16 15 13 12 10 -9 -7 -6 -4 -3 -1 0 1 3 4 6 7 9 10 12 13 15 16 18 19 21 22

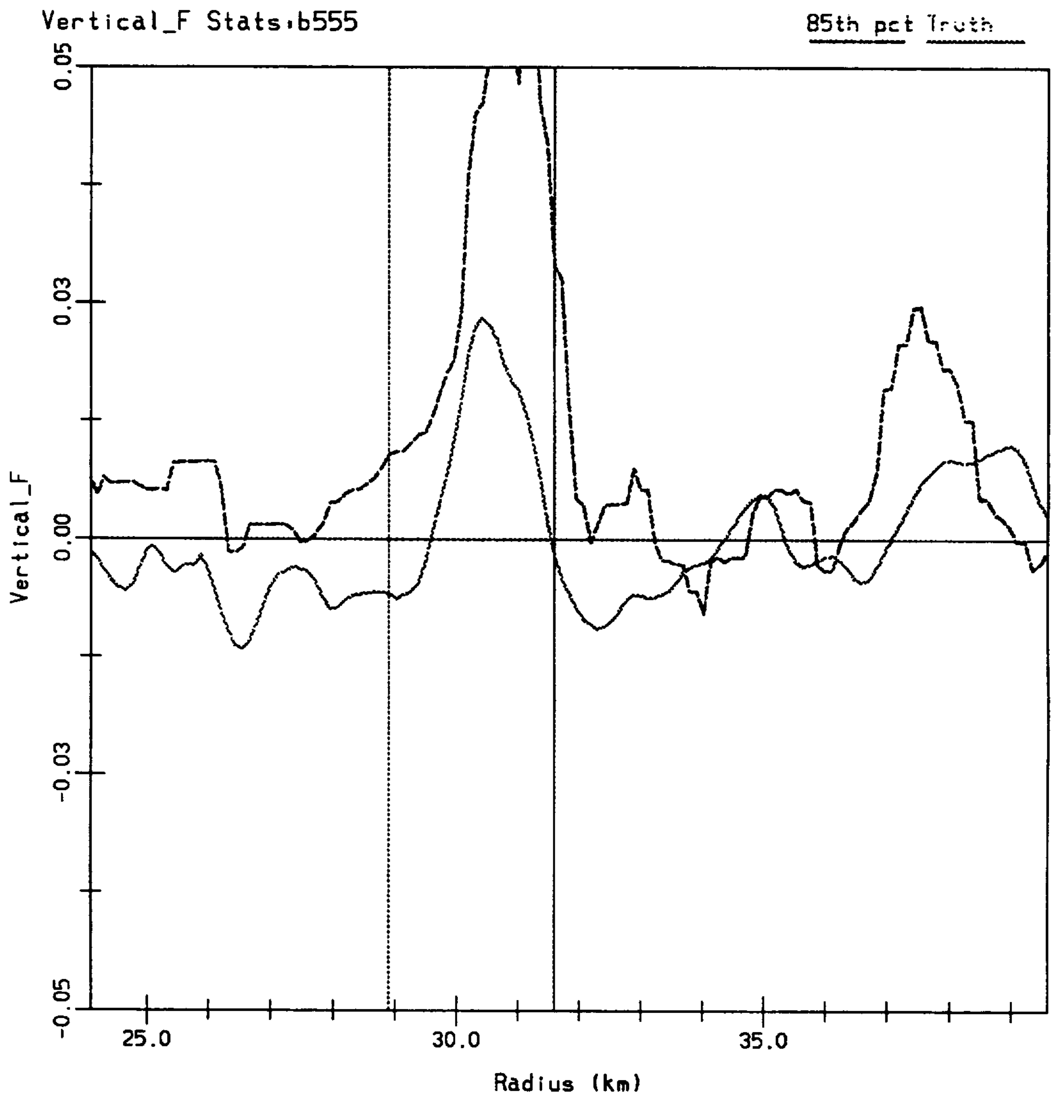

b555 Radar Data
TIME =92 08 17 22 39 09
20.0
25.0
30.0
34
-15.0
-20.0
-25.0
-30.0
0 m/s
300
15.0
20.0
25.0
30.0
92.aug.17-22.36.52
-222+191816151312 10-9-7-6-4-3-1 0 1 3 4 6 7 910121315161819 2122


Velocity Stats:b555
85th pct Truth
Velocity m/s
20.0
10.0
0.0
-10.0
-20.0
-30.0
25.0
30.0
35.0
Radius (km)

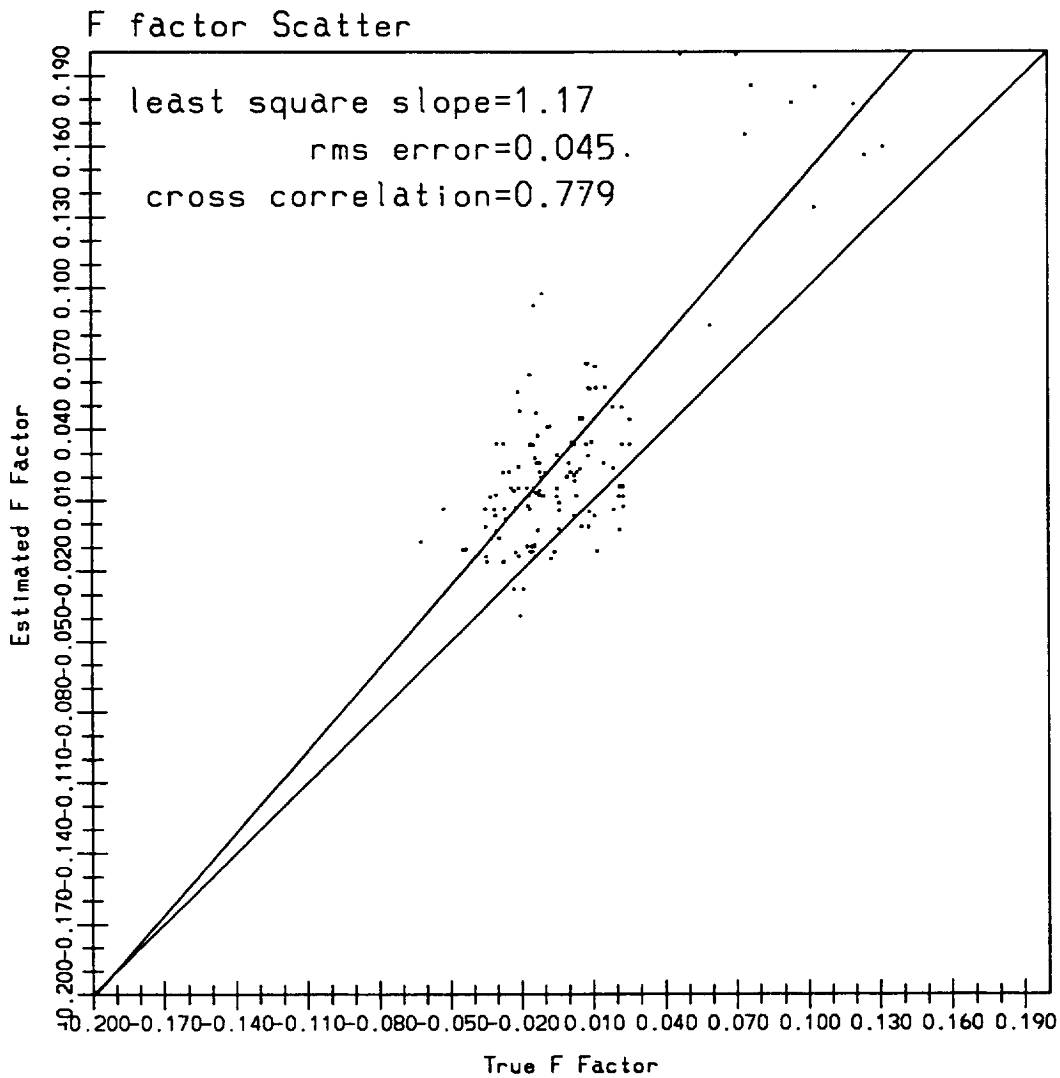

F_Factor Stats:b555
85th pct Truth
0.2
0.1
0.0
-0.1
-0.2
F_Factor
25.0
30.0
35.0
Radius (km)



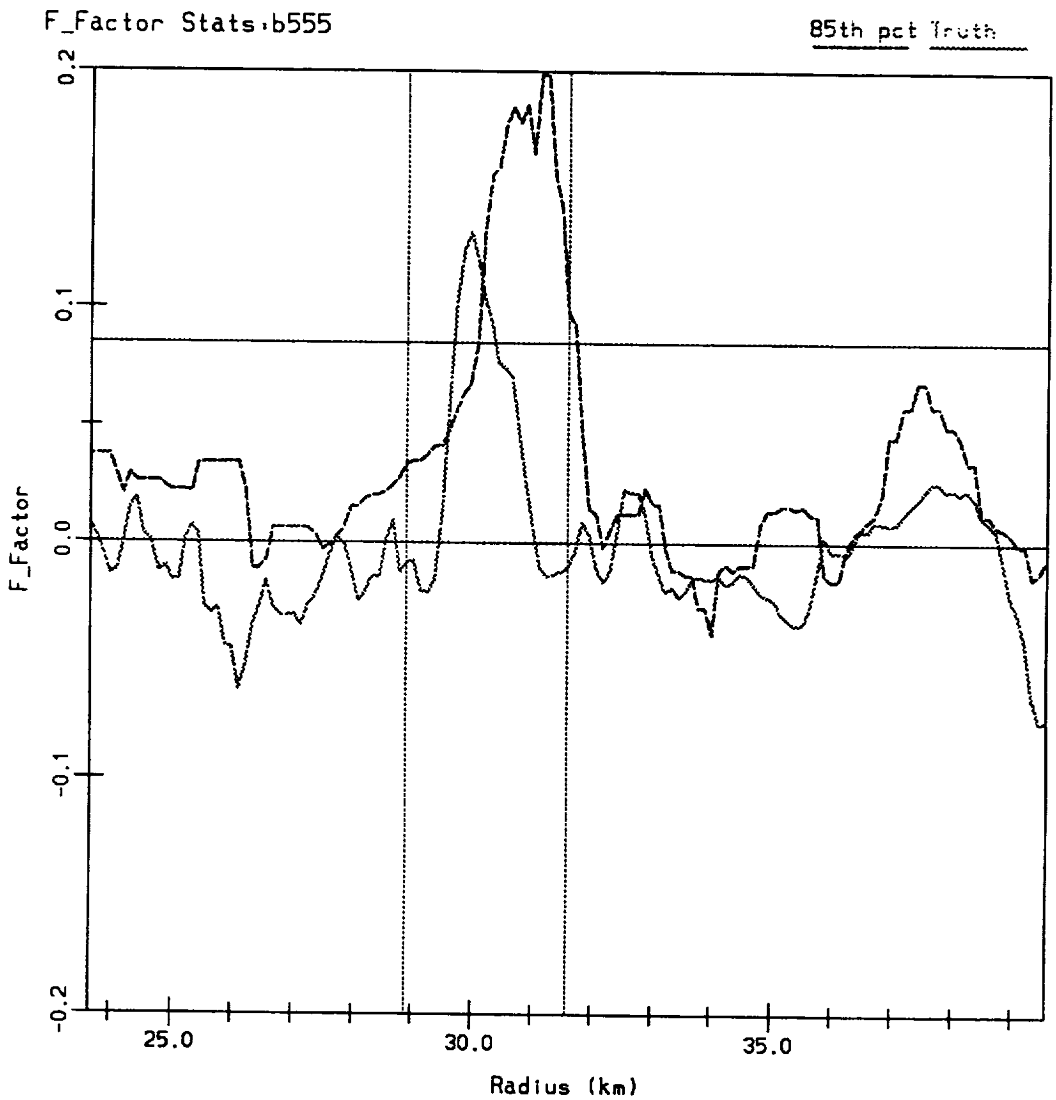
f_horiz Stats.b555
85th pct Truth
0.2
0.1
0.0
-0.1
-0.2
f_horiz
25.0
30.0
35.0
Radius (km)

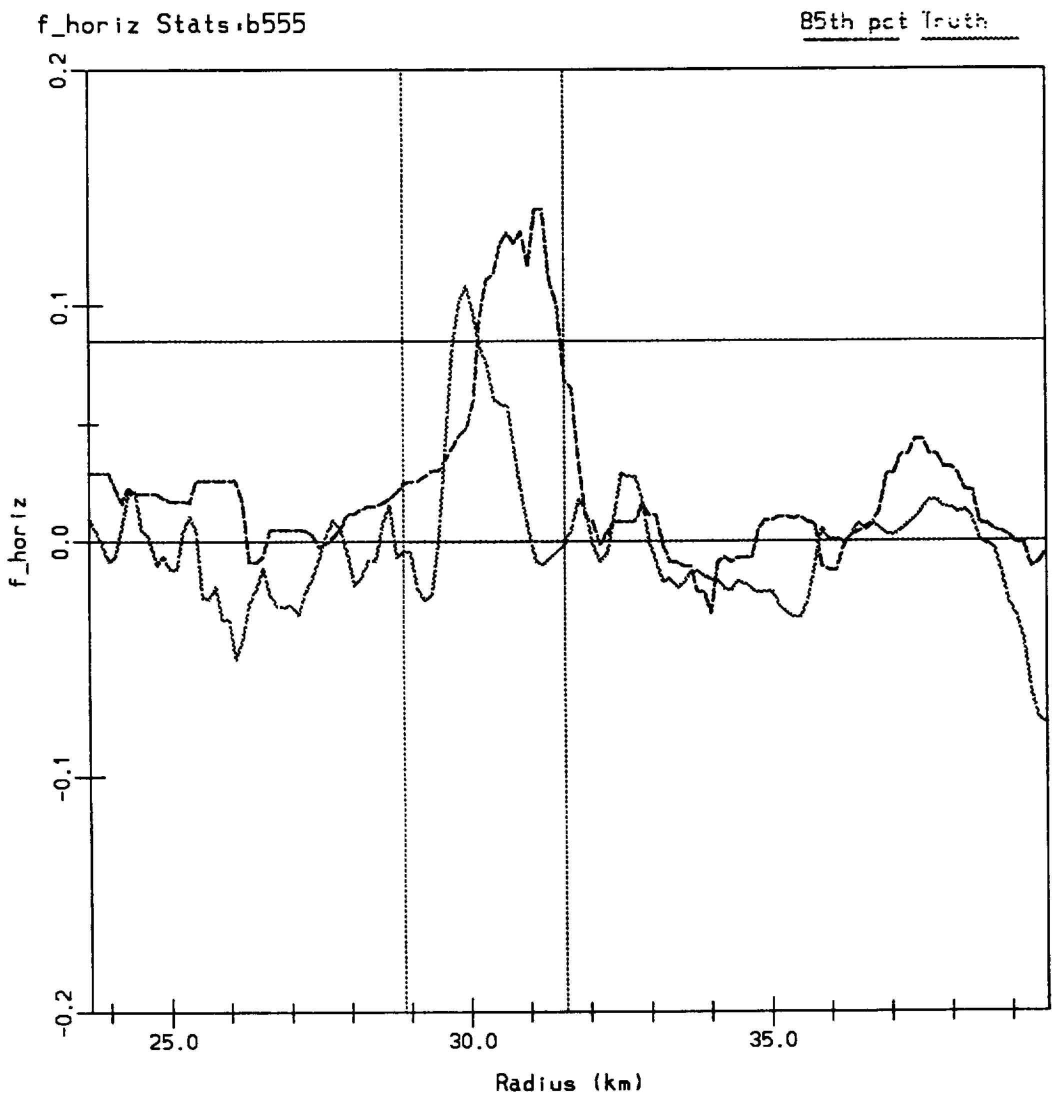


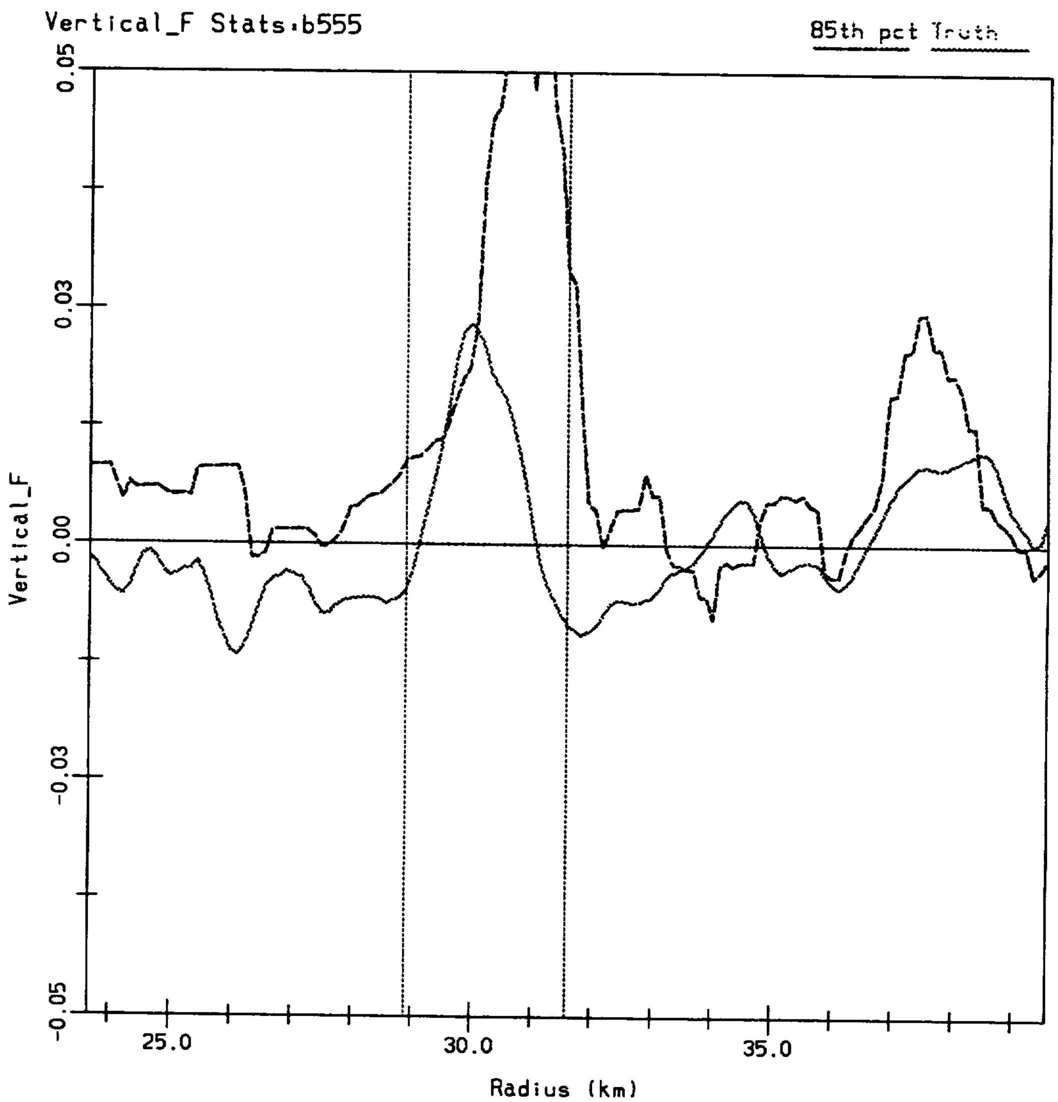
Vertical_F Stats:b555
85th pct Truth
0.05
0.03
0.00
-0.03
-0.05
Vertical_F
25.0
30.0
35.0
Radius (km)


F factor Scatter
least square slope=1.17
rms error=0.045
cross correlation=0.779
Estimated F Factor
True F Factor
-0.200 -0.170 -0.140 -0.110 -0.080 -0.050 -0.020 0.010 0.040 0.070 0.100 0.130 0.160 0.190

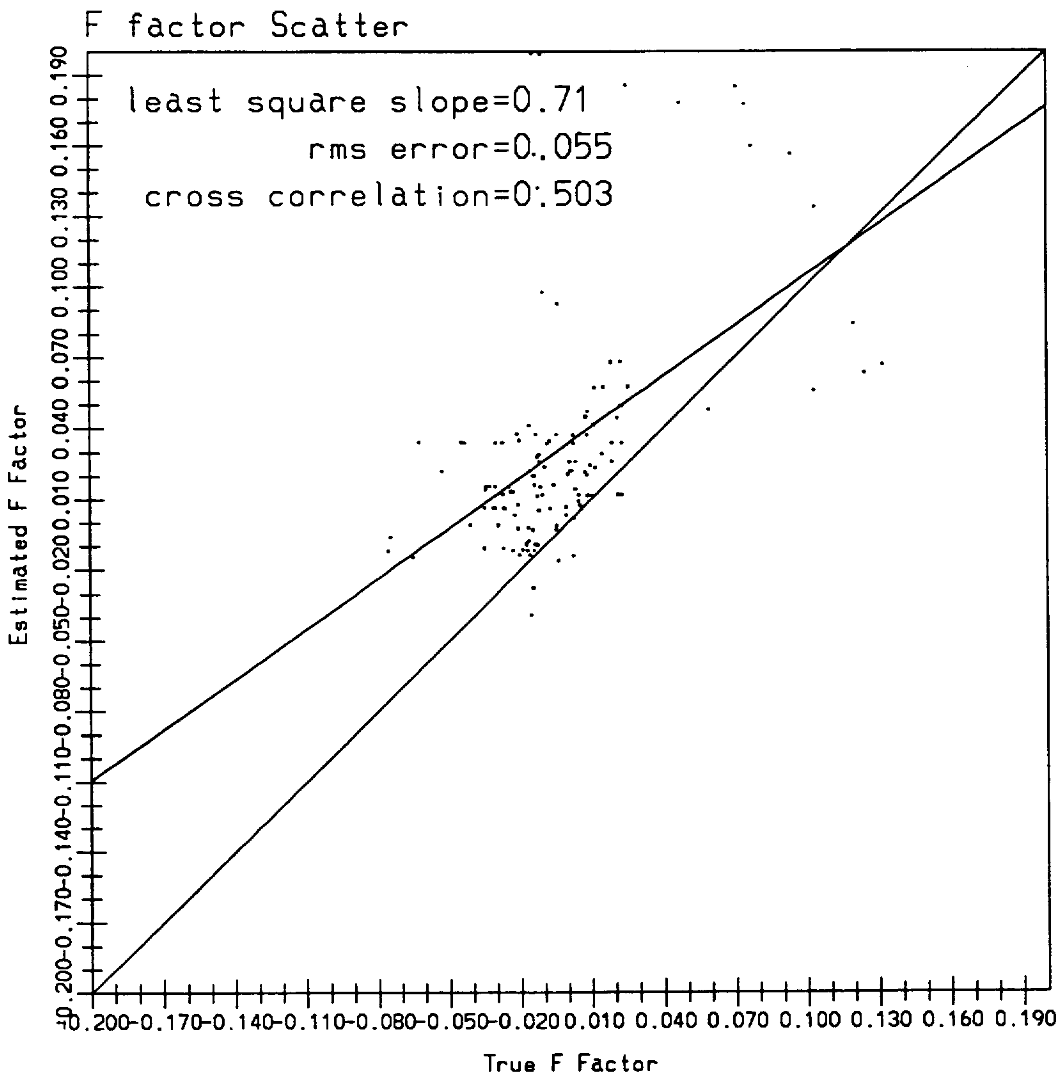
C-4.


F_Factor Stats:b555
85th pct
Truth
0.2
0.1
0.0
-0.1
-0.2
F_Factor
25.0
30.0
35.0
Radius (km)

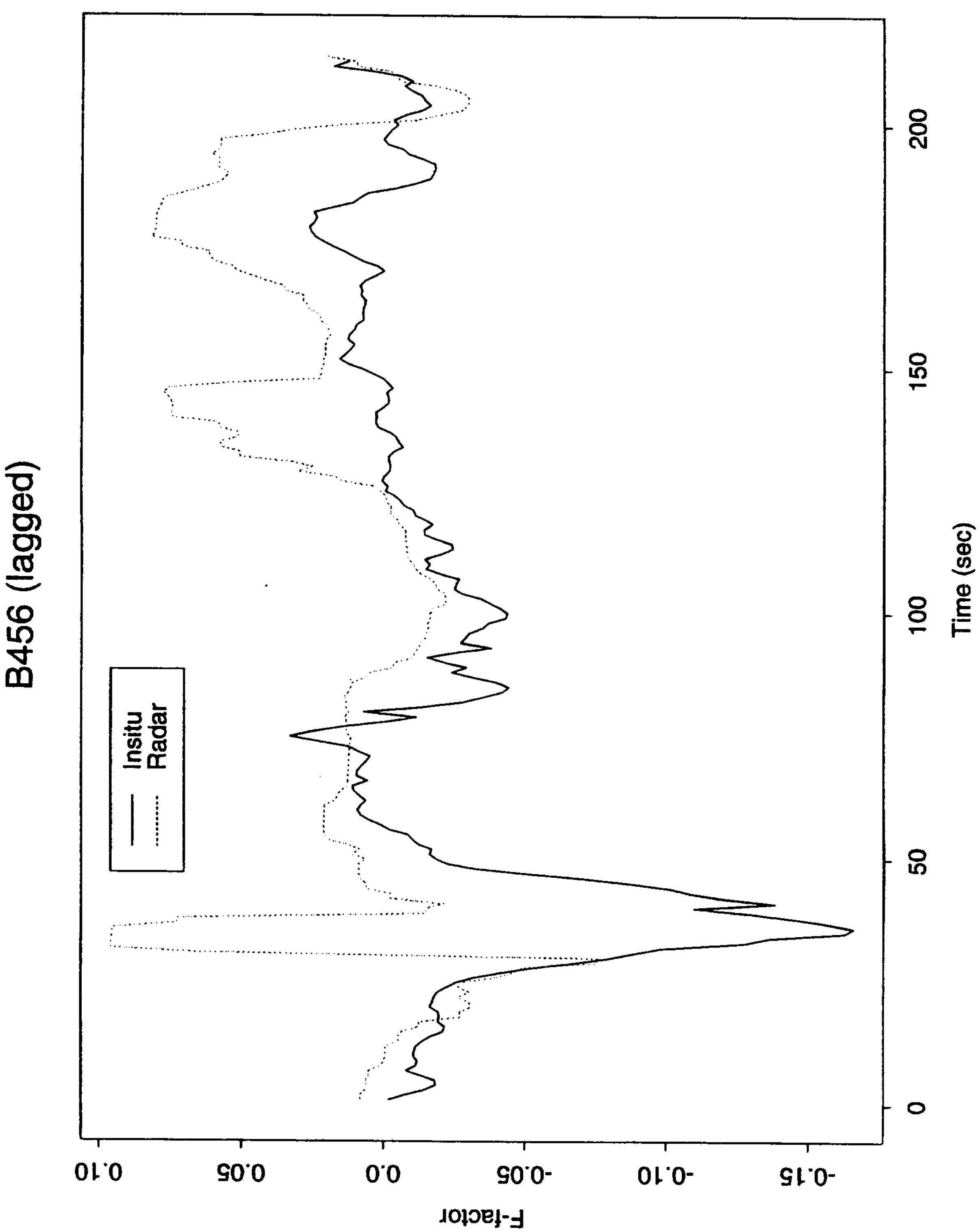

f_horiz Stats.b555
85th pct
Truth
0.2
0.1
0.0
-0.1
-0.2
f_horiz
25.0
30.0
35.0
Radius (km)

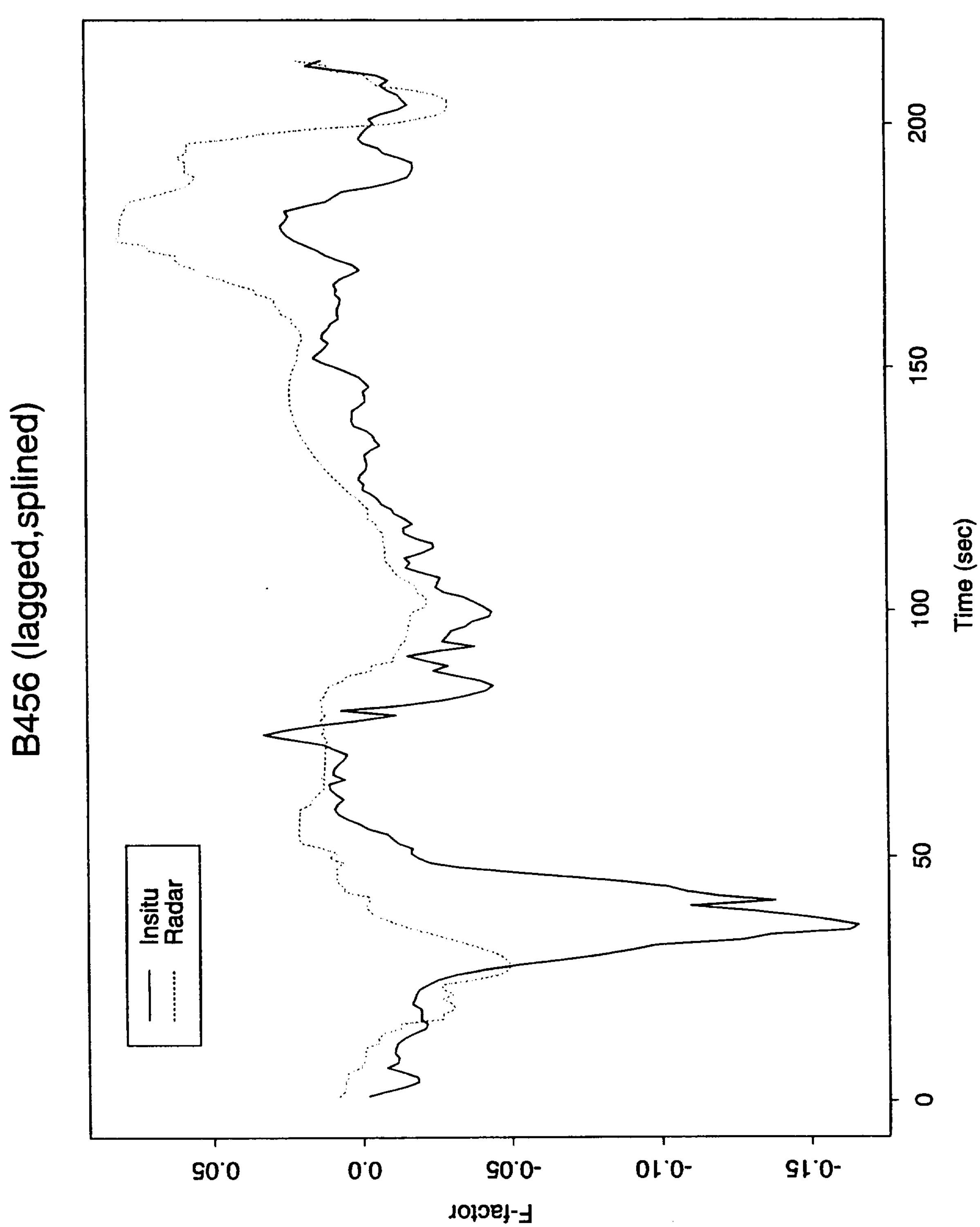


Vertical_F Stats:b555
85th pct Truth
0.05
0.03
0.00
-0.03
-0.05
Vertical_F
25.0
30.0
35.0
Radius (km)



F factor Scatter
least square slope=0.71
rms error=0.055
cross correlation=0.503
Estimated F Factor
True F Factor
-0.200-0.170-0.140-0.110-0.080-0.050-0.020 0.010 0.040 0.070 0.100 0.130 0.160 0.190


B456 (lagged)
Insitu
Radar
F-factor
0.10
0.05
0.0
-0.05
-0.10
-0.15
Time (sec)
0
50
100
150
200



B456 (lagged,splined)
Insitu
Radar
F-factor
0.05
0.0
-0.05
-0.10
-0.15
0
50
100
150
200
Time (sec)

Additional Points

Clean up the current data set; trim off regions where the aircraft path is not representative of radar beam path.

Threshold (categorize) data and compare only those cases where either aircraft of radar-derived F exceeds 0.085 (or any other threshold).

Examine F comparisons only within shapes.

Current implementation does not constitute an operational algorithm; various problems peculiar to Doppler radars must be addressed for operational implementation.

A method of translating F factor to hazard severity needs to be created.

Conclusions

Path-specific statistics show that a least squares-based method faithfully reproduces significant shears experienced by penetrating aircraft.

Microburst wind shears display local linear symmetry.

A shear-based microburst detection algorithm identifies only areas containing a quantifiable performance loss.

F contains potentially more information because it uses shear; the currently implemented algorithms discard all local shear estimates.

We believe that a shear-based F-factor algorithm is preferable to the present TDWR headwind loss-based algorithm (These findings are similar to that being proposed for ITWS).